VMASC

Research on Intelligent Synthesis Environment

NASA Cooperative Agreement NCC-1-01040 (ODURF Project 113282)

Final Report of Subproject

Dr. R. Bowen Loftin, co-Principal Investigator
Dr. David Dryer, co-Investigator
Dr. Debra Major, co-Investigator
Mr. Thomas Fletcher, Graduate Research Assistant

October 28, 2002
Virginia Modeling, Analysis & Simulation Center
Old Dominion University

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Introduction

The subproject described in the following report was funded at $80,000 and addressed assessment and continuous improvement of engineering team effectiveness in distributed collaborative environments. The work described below was carried out from April 1, 2001 through September 30, 2002 by the research team listed in the next section.

Personnel

Dr. R. Bowen Loftin, co-Principal Investigator
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Research Approach

The research team initially met with NASA Langley Research Center (NASA/LaRC) personnel to achieve a consensus on the proposed project plan and to obtain guidance from NASA/LaRC regarding a specific NASA collaborative engineering project that would be a suitable candidate for data collection. NASA LaRC recommended the Inter-center Systems Analysis Team (ISAT) as a focus for our data collection efforts.

It was generally agreed that the research team would begin by analyzing the relevant literature on collaboration with a focus on team performance in collaborative engineering. The activity would be followed by observations of ISAT activity within the context of a specific project. Following this data collection effort, an engineering team process model would be developed for the ISAT environment. Finally, this model would be used to develop recommendations for NASA/LaRC for the creation of virtual collaborative environments that could be applied to the case of the ISAT or similar efforts at distributed collaborative engineering teams conducting design and/or analysis of complex engineering systems or a system of systems.

Research Results

A detailed review of the literature of team performance was conducted and an assessment of this literature from the standpoint of distributed teams engaged in engineering design and analysis was performed. The results of this effort are documented in Annex A (A Review of Key Team Performance Processes: Implications for Engineering in Distributed Collaborative Environments).

During August, 2001 the research team observed the ISAT within the context of a specific project. The results of these observations are contained in Annex B (Team Task Analysis of ISAT – Inter-center Systems Analysis Team).

Based on both the literature review and the ISAT observations, an engineering team project model for a distributed collaborative environments was developed. This product is included in Annex C (Development and Assessment of an Engineering Team Process Model in Distributed Collaborative Environment: The Case of ISAT).

Following the development of the model described in Annex C, the model and the results of the ISAT observations recorded in Annex B were used to prepare a final recommendation for the use of distributed collaborative environments for engineering design and analysis. The recommendation was further refined to specifically apply to the ISAT environment in use within NASA. Annex D (Virtual Collaborative Environments for System of Systems Engineering and Applications for ISAT) documents this recommendation.

In addition to the four products contained in the annexes to this report, at least on journal publication is anticipated as a result of this research. In addition, a portion of the work reported here serves as the basis for the master's thesis research of a student of Old Dominion University.

Annex A

A Review of Key Team Performance Processes:

Implications for Engineering in Distributed Collaborative Environments

A Review of Key Team Performance Processes:

Implications for Engineering in Distributed Collaborative Environments

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Executive Summary

The ultimate goal of this research project is to develop a methodology for the assessment and continuous improvement of engineering team effectiveness in distributed collaborative environments. This review provides the theoretical foundation upon which subsequent empirical work will be based. Our review of the team performance literature has identified the following 12 conceptually distinct team interaction processes as characteristic of effective teams (see Table 1 on pp. 39-40 for definitions and descriptions).

- Mission Analysis
- Resource Distribution
- Leadership
- Timing
- Intra-team Feedback
- Motivational Functions
- Team Orientation
- Communication
- Coordination
- Mutual Performance Monitoring
- Back-up Behaviors
- Cooperation

In addition, this review summarizes how team task characteristics (i.e., task type, task complexity, motivation, and temporal changes), team characteristics (i.e., team structure and team knowledge), and individual team member characteristics (i.e., dispositions and teamwork knowledge, skills, and abilities) affect team interaction processes, determine the relevance of these processes, and influence team performance. The costs and benefits of distributed team collaboration are also considered. The review concludes with a brief discussion of the nature of collaborative team engineering tasks.

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Introduction

The world is growing seemingly smaller as technology advances and organizations span greater geographic distances. Teams are often used in the workplace due to task demands (i.e., an individual could not complete the task alone) and a need to remain competitive in tight markets (Ilgen, Major, Hollenbeck & Sego, 1993). Increasingly, teams are geographically disbursed and must conduct their functions across time and space (Maznevski & Chudoba, 2000). Travel is costly and often not appropriate in conditions where time is of the essence (Armstrong & Cole, 1995). Thus, team members are increasingly reliant on emerging communications technologies to perform their tasks (Hollingshead & McGrath, 1995; Ilgen et al., 1993). Yet, little is known about the performance effectiveness of distributed collaboration. Through a review of the extant literature on team performance, we will identify the salient interaction processes and features of effective teams. The processes and features identified in the review will then be applied to consider the effectiveness of teams in distributed environments and finally, will be applied to distributed collaborative engineering teams. The ultimate goal of this research project is to develop a methodology for the assessment and continuous improvement of engineering team effectiveness in distributed collaborative environments. This review is intended to provide a theoretical foundation for subsequent empirical work.

Team Performance Models

Researchers often turn to well-developed models as frameworks in constructing methodologies to better understand a phenomenon. Team performance is no exception. Numerous studies on team effectiveness have been conducted in recent decades, and several models of team performance have been developed and proven useful. Although, it is beyond the scope of this paper to provide an exhaustive review, three models will be considered. These were

chosen because of their wide use in the field, their applicability to the current project, and their relative generalizability across multiple team settings.

Team Effectiveness Model. Salas and his colleagues developed the Team Effectiveness Model (TEM) as a framework incorporating much of the team literature of the previous decade (Salas, Dickinson, Converse, & Tannenbaum, 1992; Tannenbaum, Beard & Salas, 1992). TEM has been instrumental in shaping other theoretical models in the 1990s (e.g., Dickinson & McIntyre, 1997; Weaver, Bowers, Salas & Cannon-Bowers, 1997; Urban, Bowers, Cannon-Bowers & Salas, 1995), and has received considerable empirical support (e.g., Urban, Weaver, Bowers & Rhodenizer, 1996; Urban, Bowers, Monday & Morgan, 1995). The model is an input-process-output model of team performance. See Figure 1. Simply put, four classes of inputs (i.e., task characteristics, work characteristics, individual characteristics and team characteristics) interact with one another and contribute to the performance outcome. Throughputs (e.g., team processes such as communication and coordination) mediate the input-output relationship over time. Performance of the team provides feedback to the input factors, and organization and situational factors (e.g., reward systems, environmental uncertainty) exert influence at all levels of the model.

Team Architecture Model. Urban and her colleagues (Urban, Bowers, Cannon-Bowers, & Salas, 1995) developed the Team Architecture Model as a framework for possible team design interventions to improve teamwork processes. Team architecture refers to the system factors that influence team processes by inhibiting or enhancing the interactions among the individuals. Three important factors comprise the architecture of teams, each differentially affecting the level of interaction among team members. The factors are member proximity (i.e., the physical distance between members of a team), communication modality (i.e., the medium in which

communication takes place, such as verbal, face-to-face or computer-mediated, text based) and a team's structure (i.e., the distribution of the team's subtasks among the individual members). The authors note that this list is not exhaustive, but each of these factors is certainly important in addressing member interactions, which in turn influences team effectiveness.

Task Circumplex. Teams vary greatly in the level of complexity and nature of the tasks they perform. McGrath (1984) conceived a model depicting a task classification scheme. The model, presented in Figure 2, is composed of a circle divided by four main task types occupying each of the quadrants. Each of the four categories is further divided into two sub-types. The main task types (or quadrants) are to generate, to execute, to negotiate, and to choose. The circumplex is further divided by an x- and y- axis. The x-axis represents a continuum on which tasks range from predominately cognitive to primarily behavioral in nature. The y-axis represents a continuum ranging from collaboration to conflict resolution. McGrath (1984; Hollingshead & McGrath, 1995) maintains that all variations of tasks that a team may be engaged in can be described in terms of the Task Circumplex. Further, Hollingshead and McGrath (1995) point to the lack of consistency in research in understanding the influence of technology (e.g., computer-mediated conferences) on team processes due to neglecting the variations in task complexity.

Understanding Team Performance: Collaboration Effectiveness

A team can be defined as "a distinguishable set of two or more people who interact, dynamically, interdependently, and adaptively toward a common and valued goal-objective-mission, who have each been assigned specific roles or functions to perform, and who have a limited life-span of membership" (Salas et al., 1992, p. 4). This definition is applicable to teams in many environments (e.g., command-and-control settings, aviation cockpits, and product development teams). The extant literature on team performance can be generalizable across

many types of groups working interdependently provided that key defining features of the teams are appropriate (Baker & Salas, 1997; also see McIntyre & Salas, 1995 for further review of the subject). Engineering teams often involve many specialties (e.g., mechanical, composite materials; Reid, Reed & Edworthy, 1999) and work with various functional divisions (e.g., manufacturing, marketing, finance; Hauptman & Hirji, 1996). For these reasons, engineering team effectiveness is highly dependent on the collaboration between the members of the team. Therefore it is the aim of this review to identify the processes characteristic of high performing teams and attempt to generalize those processes to engineering collaborative teams and determine which processes are applicable in distributed environments. We will also discuss the factors that are known to influence team processes, such as the team's tasks, characteristics, and composition.

Team Processes

A great deal of conceptual, theoretical and empirical research has emerged in previous decades concerning the processes of high performing teams (see Militello et al., 1999; Paris, Salas, & Cannon-Bowers, 2000). As described by the Team Effectiveness Model (TEM), processes serve an important role as throughput variables in determining team performance (Salas et al., 1992; Tannenbaum et al., 1992). Considerable overlap exists in the independent bodies of research and certain common themes have emerged. Each of twelve separate processes are defined in Table 1 and discussed successively in terms of their relevance to team performance; any empirical support is provided. The processes listed were chosen because of their theoretical distinctness. Although, similarities exist, each has subtle differences. To our knowledge, no comprehensive empirical study (e.g., factor analysis) has been conducted to determine if these processes are empirically distinct. Moreover, such a study is largely unfeasible

due to the fact that it is difficult to obtain the large numbers of teams required to appropriately perform such statistical procedures.

Mission analysis. As the operable definition of a team suggests, a goal or vision must be present to differentiate a group of individuals from a team. For a team to be effective, this goal must be clear and shared by the members (Marks, Mathieu, & Zaccaro, 2001). Further, the tasks of each individual must be aligned in accordance with the mission. For this to occur, regular attention should be placed on the status of the mission and the activities of the team (Prince & Salas, 1993). Stout, Salas and Carson (1994) found ratings of the pilots mission analysis (MA) to be significantly related to the number of targets destroyed and the overall mission performance in a low-fidelity flight simulation task. MA was assessed with items such as "devised long-term and short-term plans" and "critiqued existing plans" (Stout et al., 1994, p. 184).

Team orientation. Although attitudes are not themselves behaviors, behaviors are certainly influenced by attitudes (Petty, 1995). Team orientation refers to the attitudes that members have towards one another and the team task (Dickinson & McIntyre, 1997). Interaction among the team members is likely to be lower without an attitude of task cohesion (Zaccaro, Gualtieri, & Minionis, 1995). Further, team norms must be mutually accepted among the members for the team to succeed, and members should profit from the feeling of team membership (Dickinson & McIntyre, 1997). Harris and Barnes-Farrell (1997) found evidence for six separate processes significantly contributing to subjective performance appraisals: team orientation, team leadership, communication, monitoring, back-up behavior, and coordination.

Resource distribution. Effectively matching expertise with task responsibilities of the team is key to team performance (Fleishman & Zaccaro, 1992). Each member should be utilized maximally according to each member's resource contributions (Militello, Kyne, Klein, Getchell

& Thordsen, 1999). This implies that adjustments must be made when discrepancies exist such as reallocation of the sub-tasks due to some event (e.g., membership changes, task complexity increases/decreases, etc.).

Communication. The exchange of information is vital to the success of two or more individuals working as a team (Dickinson & McIntyre, 1997). The purpose of communication is often to clarify misunderstandings and to acknowledge the receipt of information (e.g., grounding—establishment that mutual understanding has occurred between listener and speaker) and may not always be verbal (e.g., head nods; Reid et al., 1999). Closed-loop communication is a particular sequence of exchanges whereby the receiver acknowledges receipt by a return message, often a repeat of the initial message to covey a mutual understanding (McIntyre & Salas, 1995). Empirical support exists for the amount, quality and sequencing of communication in determining team performance (Bowers, Jentsch, Salas, & Braun, 1998; Harris & Barnes-Farrell, 1997; Stout et al., 1994).

Leadership. The formal authority to lead in a team may not be vested in one member (Dickinson & McIntyre, 1997). For example, Stewart and Barrick (2000) describe relatively autonomous teams as those in which the team is reasonably free of external supervision and characterized by self-leadership shared among team members. In addition, providing leadership for the team may be a responsibility that is shared among team members, even in instances where a formal leadership role is identified. Despite who is in charge, the process of providing direction and structure to others in the team is demonstrably important in high performing teams (Dickinson & McIntyre, 1997; McIntyre & Salas, 1995; Stout et al., 1994) and can affect other processes such as decentralizing communication patterns (Stewart & Barrick, 2000).

Coordination. Effectively synchronizing and integrating the individual task activities of a team is fundamental to its success (Dickinson & McIntyre, 1997; Fleishman & Zaccaro, 1992; Marks, et al. 2001). Reid et al. (1999) express the advantage that sketching provides as a coordination function for design engineers indicating that multiple means are available for sharing and interacting with others. Turner, Turner and Horton (1999) note the advantages of sketching on a whiteboard in developing new ideas as well as updating and coordinating with other members. Brannick and his colleagues found measures of observed team coordination to be highly correlated with performance ratings and communication frequencies in a low-fidelity flight simulation task (Brannick, Roach & Salas, 1993). This suggests that many team processes are interdependent (i.e., one may influenced by the presence or absence of others).

Timing. Not only are individuals responsible for meeting deadlines in organizations, but so too are the teams in which they work. Because teams are comprised of individuals completing interdependent subtasks, effectively completing work according to prescribed timelines is critical. This process becomes more critical the more dependent the team members are on the output of other members. Sufficiently coordinating team timelines requires the pacing of both individual activities and the general organization of team resources (Fleishman & Zaccaro, 1992). This also implies a team-oriented understanding of the task. Militello et al. (1999) maintain that teams must exercise time management and engage in team planning to be effective.

Mutual performance monitoring. The need for team members to monitor the behaviors and performance of each other is a seemingly ubiquitous process in the team performance literature. Given that many team tasks are interdependent, it is essential that each member perform optimally for maximum team effectiveness (McIntyre & Salas, 1995). To compensate for deficiencies, constant vigilance is required (Militello et al., 1999). Therefore, it is not only

essential that members be individually competent in their own tasks, but also proficient in understanding the effectiveness of other team members' responsibilities (Dickinson & McIntyre, 1997). The monitoring of others' activities makes many assumptions. For example, one must be able to view and recognize the performance effectiveness of those monitored (Fleishman & Zaccaro, 1992; Militello et al., 1999). Further, this implies that members have the motivation and ability to provide feedback or support when required (Dickinson & McIntyre, 1997; McIntyre & Salas, 1995). McIntyre and Salas (1995) note that monitoring should become an implicit contract among the members to prevent feelings of "spying".

<u>Intra-team feedback.</u> Provided team members are able to engage in performance monitoring, it is expected that they should likewise be able to provide information about the status of other teammates' functioning. Feedback refers to the giving, seeking and receiving of performance related information among the members of a team (Dickinson & McIntyre, 1997). Members must wield the assertiveness and willingness to both provide and accept the criticism of others to perform effectively (McIntyre & Salas, 1995). There should be no obstacles to providing feedback of others performance such as psychological distance (e.g., rank or tenure; McIntyre & Salas, 1995). Brehmer and Allard (1991) provide evidence for the effects of feedback on decision-making tasks. They found significant increases in performance when subjects were provided task-related feedback in a command and control task. Rasker, Post and Schraagen (2000), also using a command and control task, empirically tested the effects of two types of feedback: during execution of a task and post-execution of a task. Teams performed significantly better when they were able to provide feedback during the execution of a task. Incidentally, they found that feedback provided between sessions of a task provided some performance increases, but was not as effective as the during condition. They also found

communication content to be different in the two feedback conditions. Feedback during the execution of a task consisted mostly of activity-based exchanges (e.g., communicating what each member is doing), while feedback between performance sessions consisted mostly of evaluation and determining strategy. Members providing feedback during the execution of a task seemingly knew what information needed to be exchanged.

Back-up behaviors. In addition to providing feedback, team members must also be able to provide technical assistance when gaps and inefficiencies are noted (Dickinson & McIntyre, 1997; McIntyre & Salas, 1995). Members must not only be willing to both provide help to others, but must not be reluctant to seek help when needed (McIntyre & Salas, 1995). Indeed, providing feedback and back-up assistance to others depends on adequate monitoring and proficiency in the other team members' tasks.

Motivational functions. Perhaps the most difficult to operationally define and measure (Fleishman & Zaccaro, 1992), are the functions related to developing and accepting team norms. However, team maintenance activities such as establishing performance objectives and generating task commitment are critical to team performance (Fleishman & Zaccaro, 1992). Motivating others to maintain high standards of performance may be accomplished through other processes such as feedback of individual performance or team successes (Marks et al., 2001). Marks and her colleagues (2001) have also observed that teams can dissuade members by the use of negative comments, which reduce confidence and cohesiveness.

Cooperation. Brannick et al., (1993) defined interpersonal cooperation as "the quality of team member interchanges" (p. 294). They provided validity for the construct as they measured it and demonstrated its role in performance effectiveness. Cooperation can be viewed behaviorally as conflict management or providing encouragement (Brannick et al., 1993; Militello et al., 1999).

The interpersonal processes labeled by Marks and her colleagues includes the importance of conflict and affect management of the members (2001). Effective teams should strive for harmony (Militello et al., 1999).

Task, Team, and Individual Characteristics

Each of these twelve processes described above interdependently contribute to the effectiveness of teams performing complex tasks. However, team research in the previous decade has supported the Team Effectiveness Model in its assertion that certain inputs exert influence on the need and impact of the processes in teamwork. For instance, processes will have different effects on the performance outcome depending on task characteristics, team characteristics and individual member characteristics. We review each of these influences in the ensuing sections.

Task Related Influences

Several models of team performance incorporate the nature of the task into their frameworks (see Guzzo & Shea, 1992; Salas et al., 1992). The task demands of a team and its members have many documented effects. For instance, the Team Effectiveness Model (TEM; Salas et al., 1992; Tannenbaum et al., 1992) indicates that the outcome or effectiveness of a team is affected by the inputs of task complexity, task organization and the task type. The work structure has also been demonstrated to influence a team's effectiveness (Salas et al., 1992; Stewart & Barrick, 2000). Further, Guzzo and Shea (1992) in a review noted that tasks affect performance in at least three ways: via member motivation, moderating member interaction and effectiveness, and as determinants of the requirements and interactions among the members.

Task type. The type of task that a team performs has been shown to moderate the effects of intrateam processes and performance (Stewart & Barrick, 2000). Using McGrath's (1984) task typology, Stewart and Barrick found that the performance of teams engaged primarily in

behavioral tasks was relatively unaffected by intrateam processes, whereas the performance of teams engaged primarily in conceptual tasks was significantly related to the team's processes. Steiner (1972) developed a typology that describes team tasks as either disjunctive (i.e., one exceptional member of the team can perform the task), conjunctive (i.e., performance depends on all team members' contributions), additive (i.e., performance is dependent on the summation of the members' effort), or discretionary (i.e., resources can be combined in any way). As such, task demands are moderators of member interaction and overall team effectiveness. For example, in a disjunctive task, little team process or member interaction will be needed to complete the task because it is likely that the task will be performed by the "best" member of the team. However, in a conjunctive task, interaction among the members will have a much greater influence on the team's effectiveness. Not only does the type of task influence team effectiveness, but so does the method for performing the tasks. There are multiple methods for performing some tasks, and these methods have varying effects on performance outcomes (Sauer et al., 2000).

Task complexity. Task complexity which refers to the demand characteristics of the subtasks includes variables such as time pressures/demands, amount of workload, level of information processing needed, number of dimensions a task has, and the degree to which those dimensions are prone to change (Maznevski & Chudoba, 2000; Salas et al. 1992). Many studies have demonstrated the influence of task complexity on team performance (Urban et al., 1996; Urban, Bowers, Monday, & Morgan, 1995; Zaccaro et al., 1995), and the relationship of task complexity with task organization. That is, greater complexity in the subtasks of a team necessitates greater interdependence among the members. Task organization refers to the interdependencies that exist among the subtasks (Salas et al., 1992). Interdependence of team members can best be described

by Thompson's (1967) typology. Interdependence can be pooled (i.e., little or no interaction is necessary), sequential (i.e., members are dependent on those in previous steps along a chain), reciprocal (i.e., direct two-way interactions are necessary), or comprehensive (i.e., a complex network of dependence exists among members). Related to the task organization or interdependencies is the work structure of a team (i.e., the manner in which the tasks are distributed among the members; Stewart & Barrick, 2000; Urban, Bowers, Cannon-Bowers, & Salas, 1995). The role of team structure will be discussed under team characteristics below.

Motivation. Guzzo and Shea (1992) citing Hackman and Oldham (1980) refer to the motivational characteristics of tasks. Various tasks will elicit varying levels of effort and therefore affect team performance to the extent that effort is related to performance. Weaver, Bowers, Salas, and Cannon-Bowers (1997) note that team performance is a function of both taskwork input as well as teamwork input, and there is a complex interdependence between the motivation to perform taskwork and the motivation to perform teamwork. Therefore, to fully understand team effectiveness, one must account for the role of tasks in eliciting motivation and the relationship of taskwork motivation to teamwork motivation. Ultimately, to effectively understand the relationship of teamwork processes to team performance, one must account for the nature of the tasks performed. To do so, a team task analysis is a prerequisite to the measurement of team performance (Paris et al., 2000)

Temporal changes. Having discussed the effects of variations in task type and complexity on team processes, we must address the temporal issues of tasks. Ancona and Caldwell (1990) working with new product development teams identified a series of three stages that teams progress through. The teams' predominant task activities were contrasted greatly between the three stages. They noted that product development teams have a creation phase where the

predominant activity is exploration of their own resources to discover what the team has available to them. In the second stage, development, the predominant task activity is exploitation of the resources that the team has acquired. Finally, in the third stage, diffusion and ending, the dominant activity is exportation of the product to others in the organization. Although the greater task remains the same throughout the cycle (i.e., create a new product), the interpersonal processes and intergroup relations change greatly throughout the three phases.

McGrath (1990) developed a similar temporal model of the stages and functions of teams. He contended that teams go through each of four stages (i.e., inception or goal choices, problem solving or means choices, conflict resolution or political choices, and execution or goal attainment) at each of three functional levels (i.e., production, member support, and group well-being). Different skills and processes are required at each stage and for each functional activity. More recently, Marks et al. (2001) proposed that teams cycle in a rhythm of task accomplishment. Different team processes are required of teams throughout the cycle. For instance, Marks and her colleagues argued that mission analysis is predominant during transition periods, and that coordination and monitoring are more essential in the action periods of the cycle. They also proposed that certain interpersonal processes, such as motivational functions and conflict management are essential throughout the team's performance cycle.

In yet another temporal model of design, Turner et al. (1999) describe three dimensions of transformation. In the first dimension, distributed cognition, knowledge is distributed among the team members and must become centralized. Secondly, the design stage moves from one that is provisional to a more permanent mutually agreed upon stage. Finally, the object of design must cross team boundaries and be shared with those external to the team. Turner and his colleagues believed that each of these transformations can be facilitated by emerging technologies.

Team Characteristics

The focus of the unit of analysis of team performance has shifted in recent years from the aggregate of individual performances to that of the team as a whole (McIntyre & Salas, 1995). As such, teams have unique characteristics that contribute to team performance (Salas et al., 1992). For instance, the team performance model (Nieva, Fleishman & Reich, 1978) suggests that such team characteristics as size, group cohesiveness, intra- and inter-team cooperation, and power distribution affect team performance. As already noted, the task of the team can significantly affect the team's structure, which in turn has been shown to affect team performance in various ways (Stewart & Barrick, 2000; Urban et al., 1996). Another team characteristic that has developed theoretically in the past decade is that of team knowledge. Paris et al. (2000) acknowledge that the advent of the shared mental model is in fact the "hallmark of the nineties" regarding team research. Our focus will be on the team characteristics, structure and knowledge.

Team structure. The structure of a team refers to the distribution of the subtasks, responsibilities, and authority among the individual members of the team (Salas et al., 1992; Stewart & Barrick, 2000). Subtasks may be distributed in a manner that several members perform the same task (i.e., redundancy) to ensure adequate performance (Salas et al., 1992), or the subtasks may be distributed such that individual members perform independent subtasks given their various expertise (Hollenbeck et al., 1995). Further, teams may be differentiated in their structure by a hierarchical distribution (i.e., team members hold unique expertise and are subject to a formal chain-of-command) or non-hierarchical distribution (i.e., individual team members are non-specialized and share common information and capabilities; Urban, Bowers, Monday & Morgan, 1995). Indeed, the task largely determines the structure of a successful team.

It may not be feasible for some complex tasks to be performed by many members of the same team, nor can all members of a team possibly possess all the needed knowledge to perform the task in its entirety. This is perhaps the initial appeal of using teams in organizations in the first place.

Structure is an important factor influencing team processes. The effective team structure will alleviate the workload burden of a team's members by allowing the members to share responsibilities (Salas et al., 1992). Several studies have found an overall performance advantage in nonhierarchical structures (see Urban, Bowers, Monday & Morgan, 1995), albeit nonhierarchical structures are not always practical. Further, the structure of a team can affect the communication structure as well as other coordination processes that exist within the team (Stewart & Barrick, 2000; Urban, et al, 1996; Urban, Bowers, Monday & Morgan, 1995). For instance, a team structure that encourages self-leadership or autonomy may induce a decentralized communication structure that will in turn affect performance. This effect, as previously noted, will be moderated by the task type (e.g., self-leadership is associated with higher performance in conceptual tasks – but, self-leadership is associated with diminished performance on behavioral tasks; Stewart & Barrick, 2000).

Team knowledge. Team knowledge refers to the collection of task- and team-relevant knowledge held by the team members and their collective understanding of the current situation (Cooke, Salas, Cannon-Bowers, & Stout, 2000). According to Cooke and her colleagues, team knowledge is a component of the greater construct team cognition, which encompasses such phenomena as team decision-making, team vigilance, team situation awareness and team knowledge. Team knowledge also contains two subsets: team mental model (TMM) and team situation model (TSM). The TMM can be defined as the collective task- and team-relevant

knowledge that the team members bring to a situation. TMM is generally long-lasting, acquired through training or experience and exists prior to specific tasks. TSM is defined as the collective, dynamic understanding of a specific situation. In contrast to TMM, TSM is more fleeting and dynamic, situation specific and acquired during the completion of a task. Research has provided evidence that team performance is maximized when knowledge is accurate and appropriately distributed among the team members such that appropriate strategies can be utilized to cope with the team tasks (for review see Cooke et al., 2000; Paris et al., 2000). Shared team knowledge is also thought to enable implicit coordination and increase communication efficiency among team members when explicit communication/coordination is hindered (Cooke et al., 2000; Rasker et al., 2000; Marks, Mathieu, & Zaccaro, 2000; Stout, Cannon-Bowers, Salas, Milanovich, 1999). Shared knowledge also contributes to vision clarity and stability (Lynn & Reilly, 2001; Lynn, Reilly & Akgün, 2000), which could lead to better performance.

Several recent studies have demonstrated methods for fostering team knowledge and addressed the effects of team knowledge on team performance. Stout and her colleagues (1999) demonstrated that prior planning enhanced the shared mental models of teammates, which resulted in more efficient communication and information passing in advance of explicit requests, enhancing performance in high-work load situations. Similar to planning is the role of leader briefings. Marks et al. (2000) demonstrated that pre-mission leader briefings enabled the development of mental models that in turn affected communication processes and flexibility in novel settings. They further demonstrated that knowledge similarity was more important for team effectiveness than initial knowledge accuracy. Another study demonstrating the link between the TMM and team processes was conducted by Rasker et al. (2000). This study showed the effects of two-types of intrateam feedback on TMM – performance monitoring (i.e., feedback

during the activity) and team self-correction (i.e., feedback between performance sessions). Teams engaged in performance monitoring were much better informed of the situation and better able to adapt to the team task. Self-correction was shown to be better than no feedback, but not as effective as the ongoing communication of performance monitoring that allowed the continuous updating of the TMM. In an attempt to better understand the knowledge management of effective new product development teams, Lynn and colleagues (Lynn & Reilly, 2001; Lynn et al., 2000) noted that high performing teams have strategies for recording, reviewing and filing of project information in a manner that can be later retrieved. This assists in maintaining the team's vision clarity and leads to vision stability.

Individual Team Member Characteristics

To this point, we have maintained the focus on the team in the aggregate, the team processes, the role of the team task and the characteristics of the team. However, no understanding of team performance would be complete without addressing that which composes the team – the individuals. Individual team members bring many attributes to the team setting. First, team members must have the knowledge, skills and abilities (KSAs) to perform their technical tasks effectively. Aside from the technical KSAs however, individuals contribute in their dispositions (e.g., personality traits, general cognitive abilities, etc.) and their teamwork KSAs (LePine, Hollenbeck, Ilgen & Hedlund, 1997; Neuman & Wright, 1999; Stevens & Campion, 1994; 1999).

Dispositions. A considerable number of studies have shown the relationship of individual task performance with relatively stable characteristics such as general cognitive ability (*g*) and personality traits (see LePine et al., 1997). However, only recently have studies begun to view the relationship of such traits with team performance. For example, *g* has been shown to be

related to individual performance measures, and in at least two studies using a conjunctive model (i.e., performance is dependent on the weakest link) *g* was shown to be modestly related to team performance (LePine et al., 1997; Neuman & Wright, 1999). Low leader *g* was found to stifle the effects of high *g* in the team members in teams with low horizontal substitutability (i.e., little redundancy of tasks; LePine et al., 1997). However, LePine et al. found that even when horizontal substitutability was low, teams with low *g* (i.e., a member with low *g*) were able to compensate for the team deficiency by altering communication patterns. Having one or two members high in *g* resulted in anticipating the communication needs of those low in *g*. This compensatory behavior was not found for teams low in conscientiousness.

Conscientiousness is a relatively stable personality trait with the sub-categories of competency, dutifulness, achievement, and self-discipline (Neuman & Wright, 1999). In a study of teams of human resource workers, Neuman and Wright (1999) found conscientiousness to be significantly related to both task performance and work accuracy above that which *g* and individual technical KSAs would have predicted. Agreeableness was also found to be positively related to task performance. Agreeableness is a personality trait representing general quality of interpersonal interactions consisting of the personality facets trust, straightforwardness, altruistic, compliance, modesty, and tender-mindedness (Neuman & Wright, 1999). This personality trait was also significantly positively correlated with measures of interpersonal skills. In addition to *g*, conscientiousness, and agreeableness, other research has demonstrated that assertiveness in the team members is essential to team performance. For instance, team members must show a willingness to provide backup behaviors when needed (McIntyre & Salas, 1995) and make suggestions when appropriate (Stout et al., 1994; Prince & Salas, 1993).

Teamwork KSAs. Previous work by Stevens and Campion (1999, 1994) identified and validated two main dimensions of teamwork KSAs: interpersonal KSAs and self-management KSAs. They investigated these KSAs because (1) they could be trainable, unlike dispositions and cognitive abilities, and (2) they could be used in personnel selection. The interpersonal KSAs include sub-categories of conflict resolution, collaborative problem solving and communication KSAs. Each of these sub-categories includes specific knowledge, skills and abilities needed for optimum team effectiveness (e.g., recognize obstacles to collaborative group problem solving and implement appropriate corrective actions). Seat and Lord (1998) identified similar "soft skills" as necessary components of interaction among engineering problem solvers and developed a training initiative that incorporated such skills as interviewing, questioning, exchanging ideas, and managing conflict. In addition to these interpersonal KSAs, several studies have cited the adaptability and flexibility of the team members to cope with situational and task demands as an important interpersonal KSA (Marks et al, 2000; Stewart & Barrick, 2000; McIntyre & Salas, 1995; Stout et al, 1994; Prince & Salas, 1993).

The second main dimension of teamwork KSAs identified by Stevens and Campion (1999, 1994) are the self-management KSAs. Subcategories of the self-management dimension include goal setting and performance management, and planning and task coordination. Again, each of these sub-categories has specific KSAs associated with effective team performance (e.g., to monitor, evaluate, and provide feedback on both overall team performance and individual team member performance). This latter example of a specific KSA implies that the members have adequate inter-positional knowledge (i.e., the knowledge of the roles of other members of the team: Urban, Bowers, Monday & Morgan, 1995). The absence of this knowledge, called inter-positional uncertainty (IPU), has had negative effects on team processes and performance

(Urban, Bowers, Monday & Morgan, 1995). In addition to these KSAs, team members must exhibit the willingness or motivation to perform the needed teamwork behaviors (Weaver et al., 1997; McIntyre & Salas, 1995).

Distributed Collaboration

Recent technological advances have enabled teams to work in a distributed fashion. This has increased economic competitiveness in organizations for many reasons (see Ilgen et al., 1993). Collaboration has been defined as two or more people working together for common work related outcomes (Horrocks, Rahmati & Robbins-Jones, 1999). We extend to this the notion of distributed collaboration to mean working on a common task while separated by distance. Whether collocated or distributed, members of teams must perform the tasks required of the team. Both the technical tasks and the above mentioned teamwork tasks (i.e., team processes) must be fulfilled. However difficult it is to learn and exhibit teamwork processes in a collocated environment, teams that are distributed must overcome those challenges as well as dealing with emerging technologies (e.g., communication, shared workspace, and shared library technologies; May & Carter, 2001), and other issues involving non-face-to-face interactions (e.g., spontaneous encounters, modeling of mentor behavior, etc.; Armstrong & Cole, 1995). Horrocks et al. (1999) identified many potential reasons for collaboration, some of which are not captured in common notions of tasks. Their framework proposes that teams meet for externalities (i.e., ceremony, statutory), problem solving (i.e., identification, idea generation, etc), and support processes (i.e., coordination, socialization, motivation, etc.).

Collaboration can be viewed in terms of a hierarchy of activities. Relying on Activity Theory,[2] Bardram (1998) illustrated three levels of collaboration: co-ordinated, co-operative, and co-constructive. Co-ordinated collaboration refers to the normal routine interactions of

individuals working from the point of view of the individual. Co-operative collaboration requires more interaction among the individuals working interdependently. Co-constructive collaboration refers to the collective re-conceptualization of the task objective. Each varies in the level of interdependencies and levels of awareness required of the participants. Therefore, tools aimed at supporting collaboration should be dynamic to the extent that the collaborative activities range in the hierarchy.

Computer Supported Cooperative Work

Computer supported cooperative work (CSCW) is an emerging body of research on the use of technology to support and enhance communication and other organizational activities (Olson & Olson, 1997). CSCW can typically be divided into four main categories of support systems: communication; shared workspace & mutual awareness; shared information & information management; and group activity support (May & Carter, 2001), and should be studied in the aggregate (Olson & Teasley, 1996). Because technology is growing at an exponential pace, the research on the effects of each of these support mechanisms is somewhat lacking. However, we can make limited conclusions about the effects of some technologies and communication (Hollingshead & McGrath, 1995). Which technology should be implemented and utilized depends largely on the task (e.g., generating ideas or executing performance tasks) (Hollingshead & McGrath, 1995), stage of team task (e.g., problem solving or execution stages; Ancona & Caldwell, 1990; May & Carter, 2001; McGrath, 1990), and the level of media richness required of the task (Maznevski & Chudoba, 2000). Further, ease of use should be addressed when implementing such support systems; technology does not help when the tools themselves further burden the already busy team members (Jude-York, 1998). In fact, some teams can be disbursed not by geographic distances, but by their individual workloads (Jude-York, 1998). Olson and

Teasley (1996) cite the need for management to support the use of new technologies implemented in any organization. They found teams to vary their level of task interdependencies based on the barriers the members encountered from various technologies. This implies that if the employees meet challenges without support of the tool use from management, the task interdependencies envisioned will suffer.

Hollingshead and McGrath (1995) conducted an extensive review of the computer-mediated communication (CM) literature and made several conclusions.[1] Overall, CM generates less communication units and each unit is filled with less socio-emotional content resulting in the filtering of extraneous information. There is also an apparent equalization of the participation in the communication patterns (i.e., less participation from verbose members). Messages tend to become uninhibited, a phenomenon known as "flaming," when perceptions of conflict arise (presumably due to lost socio-emotional content and relative anonymity). CM has also been viewed (depending on the task) as a more productive mode of communication (Sauer et al., 2000).

Although few studies have taken integrated approaches (i.e., viewing the effects of combined technologies), some have addressed differences between face-to-face interactions and the use of multimedia technologies (MM: includes, video, audio, text, and graphics for example). Sauer and his colleagues (2000) for example found that teams using MM performed remarkably similar to teams operating face-to-face in a knowledge acquisition task. The teams functioning with MM took longer on average than teams operating either face-to-face or in CM conditions, but results were dependent on the method for engaging in the task (i.e., structured interviewing was poorest in the MM condition, whereas a network technique of knowledge acquisition was superior in the MM condition). By viewing collocated engineering design teams, Reid et al. (1999) determined

that a shared workspace for visual representations, audio for communication, and a means to point were sufficient for effective collaboration. In the engineering design teams, a visual contact of the speaker was only needed for grounding (i.e., ensuring that the listeners understand what is being said), which could be done by a pointing device on the visual display. May and Carter (2001) note that static images are found to be preferred over poor quality video in automotive product design teams. Video was primarily used for initial meetings and was later placed in the background of the workspace. In fact, Reid et al. (1999) suggest that only a "small proportion of the activities of design teams requires the processing power and advanced display technologies currently under construction…"(p. 255). However, Brannick, et al. (1993) observed that remote evaluators rating audio transcripts viewed team processes differently than did on-site visual observers of collocated teams. This indicates that some visual, non-verbal interaction influences ratings of team processes.

Team Process Barriers in Distributed Environments

Technology issues aside, there are several difficulties that have been observed in distributed teams that should be addressed to enhance performance. Armstrong and Cole (1995) reported on their observations of teams residing in a fortune 100 company during the course of their interviews and consultations with the firm. We will report on four main areas of concern for distributed teams: spontaneous encounters, modeling behavior, out-of-sight issues, and, recognizing and resolving conflicts. Collocated team members have an immediate advantage over distributed members in that chance encounters are able to occur which results in informal discussion, feedback, and decision-making. These spontaneous encounters greatly reduce misunderstandings, and shorten the time spent in formal meetings resolving the more mundane issues. Recent approaches to technology development may be able to address this issue with

applications such as an electronic virtual "foyer" (Benford, Brown, Reynard & Greenhalgh, 1996). A natural foyer serves many purposes for an organization such as the public face of the building, entranceways to the organization, and public meeting places. An electronic foyer should serve the same purposes. Armstrong and Cole also note the value of modeling to the newcomer of an organization. Both newcomers and subordinates alike are at a significant disadvantage if they are not able to model their mentor's behavior. In addition, distributed members are often left out of important discussions, even when all members are engaged in a formal team meeting. Apparently, collocated cultures emerge and dominant members tend to forget to include the distributed members in remote conferencing. Finally, conflicts are often unrecognized and therefore go unresolved for lengthy periods. When managers can see the problem (i.e., when subordinates are collocated), the problems can be resolved quickly, but managing distributed members is no easy task. Unresolved conflicts lead to more intense future encounters and feelings of distance from the team's core. In her study of three teams utilizing the same technologies, Jude-York (1998) demonstrated that CSCW systems can provide the technological support, and the team could still fail. This indicates the importance of social and process issues in teamwork.

Potential Benefits of Distributed Environments

We have demonstrated the many pitfalls associated with distributed collaboration such as technological challenges and social issues, but there are perhaps as many compelling reasons to further explore collaborating in distributed environments as there are disadvantages. For instance, there are practical and strategic competitive advantages for enabling distributed collaboration (see Ilgen et al., 1993). Further, using the various technological support systems can have individual advantages such as filtering extraneous information (e.g., Hedlund, Ilgen, &

Hollenbeck, 1998) and enabling asynchronous work. Several studies have proposed that effective distributed teams make use of such advantages as the appropriate technologies for communication and knowledge sharing (May & Carter, 2001; Maznevski & Chudoba, 2000; Sauer et al., 2000)

The practical advantages for distributed collaboration are many. First, it may not be feasible for members of a distributed team to be physically present for certain phases of a task (e.g., team members who are also members of other teams may not be in two geographically separated locations in the same time period). Entire days are often lost in travel for a meeting that could have occurred via some technologically supported means. Travel costs are also a consideration in determining economic competitiveness. It has been estimated that geographically distributed product design teams making use of technology have reduced the time to market by as much as 50% (May & Carter, 2001; Jude-York, 1998), which can reduce costs by millions of dollars and increase sales volume by billions of dollars in the automotive industry.

Technology not only alleviates the problems of geographic differences, but also may enhance some communication by filtering extraneous info and allowing messages to be transferred asynchronously. For example, in decision-making tasks, Hedlund and her colleagues (1998) found hierarchical sensitivity (i.e., the extent to which the team's leader appropriately weighs members' recommendations in arriving at his or her decision for the team) to be greater in CM teams than in teams operating face-to-face. However, they found team informity (i.e., the extent to which all information potentially available to the team is actually acquired by those staff members who need it) and staff validity (i.e., the degree to which staff members' recommendations are predictive of the correct team decision) to be higher in face-to-face teams.[3] This indicates that the same communication mode may both enhance and inhibit factors leading

to "correct" decision-making. Others have noted the benefits of the relative anonymity afforded by the use of computer-mediated support systems (Bikson & Eveland, 1996). For instance, meeting anonymously obscures status differences, which enhances the input of members performing a divergent task (i.e., generating ideas, plans etc.). This effect is not as positive in conducting convergent tasks however (i.e., not all members have an equal voice in decision-making, voting etc.).

When assessing the benefits of CSCW, one should always be aware of the levels of analysis (e.g., individual, team, organization, industry) because what may benefit the team may be an inconvenience to the member and vice-versa (Olson & Olson, 1997). For example, team members are often inconvenienced by the implementation and the maintenance required of knowledge management systems (Jude-York, 1998). Gutwin and Greenberg (1998) also point to the issues concerning control of shared work objects. This is to say, designers of shared workspaces should keep in mind the level of control—should each individual or the group have control of workspace navigation, artifact manipulation, and view representation? The team task dictates the response to this dilemma.

Effective distributed collaboration requires that the task be matched with the appropriate technology available (Maznevski & Chudoba, 2000; Sauer et al., 2000). This is to say that the media richness required of the task should be matched with the media richness available by the supporting technology. Maznevski and Chudoba (2000) propose that for effective teams, task complexity will dictate the number, mode, and complexity of communication incidents. Future work on asynchronous communication should address the problems associated with redundancies and member awareness. For example, when team members collaborate via e-mail, members often forget the context of each message requiring the reader to have to re-read

previous messages. (Neuwirth, Morris, Regli, Chandhok & Wenger, 1998). Neuwirth et al. demonstrated the benefits of using task-tailorable messaging systems to greatly reduce redundancies and enhance member awareness. Technologies such as information libraries are also allowing teams to reduce redundancies and focus on problem-solving and decision making in team meetings rather than being bogged down by mundane issues of bringing the other members up to date; this also allows for part-time teammates to stay abreast of the team functions (Jude-York, 1998; Lynn & Reilly, 2001; Lynn et al., 2000). Maznevski and Chudoba also suggest that distributed teams should develop a rhythmic pattern of regularly scheduled (preferably face-to-face) encounters. The distance between these encounters can be increased to a year or more if the members share a common view of the task, have strong relationships and commitment to the team, and regular meetings utilizing a less rich medium are conducted. The effects of spatial distances and technological advancements on team functioning and performance are summarized in Table 2.

Engineering Tasks

The ultimate purpose of this review is to provide a foundation for understanding the critical team processes that contribute to the effectiveness of collaborative engineering teams in distributed environments, so that a methodology for the continued assessment and improvement of the overall effectiveness of such teams can be developed. For collaborative engineering teams, and indeed for all teams, a team task analysis is critical to assessing and improving team performance (Paris et al., 2000; Salas et al., 1992). Team task analysis requires an adequate understanding of the individual subtasks that the team performs and an examination of the pertinent teamwork processes that are needed for the success of the team. This is to say, we need to know what engineering teams do and how they do it. Engineers typically are engaged in the

design, re-design, or assessing the feasibility of products (May & Carter, 2001; Reid et al., 1999; Sauer et al., 2000). In designing products, methods for acquiring the expert knowledge of others are highly useful for the engineering team (Sauer et al, 2000; Seat & Lord, 1998). Due to increasing task complexities and competitive market conditions, teams of specialists are often employed for the creation, development, and diffusion of products (Ancona & Caldwell, 1990). Teams of specialists often are comprised of engineers from various domains such as mechanical engineering, composite materials engineering, and engineering systems among others (Reid et al., 1999), which work along side functional specialists from different organizational areas (e.g., manufacturing, marketing, finance; Hauptman & Hirji, 1996; May & Carter, 2001; Sauer et al., 2000).

Through a process known as concurrent engineering (CE), cross-functional teams are able to simultaneously design, manufacture, test and support various products greatly enhancing the firm's economic competitiveness (Hauptman & Hirji, 1996). In CE, designers are often required to maintain a collaborative relationship with suppliers, manufacturers, distributors and the corporate center (May & Carter, 2001). These relationships demand adequate team processes for effective performance. Further, geographic challenges often lead to the need for distributed collaboration. Hauptman and Hirji (1996) suggest that information flow is significantly related to meeting project budget and temporal goals in CE. Lynn and his colleagues (Lynn & Reilly, 2001; Lynn et al., 2000) recommend that new product development teams establish a knowledge management sequence that involves the adequate recording and filing of the team's knowledge so that future reviewing is possible. Sufficient knowledge management has been demonstrated to contribute to increasing vision clarity and stability among the staff and to decrease the time to market for new products (Lynn & Reilly, 2001; Lynn et al., 2000; May & Carter, 2001). The

above is only a cursory description of the tasks that engineers perform. As the field of engineering is vast, so too are the tasks relevant to engineering collaboration. However, McGrath (1984) has provided a common framework with which to categorize tasks that engineers in specific teams perform. Using the above review, and an adequate task analysis, a model of effective engineering collaboration will be developed.

Summary

Through our review of the literature on team performance we have identified twelve theoretically distinct functions that we believe are salient to the effectiveness of teams in generalized settings; these are presented in Table 1. Several relevant factors were discussed that should be addressed when mapping the team processes mentioned above to any specific team. Therefore, we noted that the processes are relevant to all teams; however, their importance in individually determining performance depends largely on factors such as task characteristics, team characteristics, individual influences, and the like.

We also determined that distributed teams have unique issues that technology can both encumber and enhance. These factors are summarized in Table 2. Although future research should explore each issue and technological advancement in contributing to team performance, we have provided a cursory summary of the research to date. We intend to use this review as a prelude to the development of a model of effective distributed team performance. Coupled with an adequate task analysis of engineering collaborative teams, we will develop a methodology for the assessment and continued improvement of distributed collaborative engineers. Such a methodology will be useful in providing a framework for the advancement of future collaborative technology and distributed team effectiveness.

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Footnotes

[1] CM in this context generally refers to text-based transfers of information.

[2] For a review of activity theory see Bardram (1998).

[3] The interested reader is directed to Hollenbeck, et al. (1995) for a complete discussion of the effects of these factors on decision-making.

Table 1.

Processes of effective teams.

Team processes	Definition / Description	Relevant sources
Mission analysis	The interpretation and evaluation of the team's mission, including the identification of its main tasks as well as the operative environmental conditions and team resources available to mission execution. Similar to vision/goal clarity.	Marks et al., (2001) Stout et al., (1994) Prince & Salas (1993)
Team orientation	The attitudes that team members have toward one another and the team task. Reflects the acceptance of team norms, the level of cohesiveness, and importance of team membership. Success depends on interaction. Team spirit and morale.	Dickinson & McIntyre (1997) Harris & Barnes-Farrell (1997) Zaccaro et al. (1995) Brannick et al. (1993)
Resource distribution	Decisions regarding the distribution of roles, responsibilities and functions to individual members. Allocation of resources such that all members are efficiently utilized.	Militello et al., (1999) Fleishman & Zaccaro (1992)
Communication	The exchange of information by 2 or more members. Closed-loop communication ensures the proper receipt and understanding of the information.	Reid et al. (1999) Bowers et al., (1998) Dickinson & McIntyre (1997) Harris & Barnes-Farrell (1997) McIntyre & Salas (1995) Stout et al., (1994)
Leadership	Involves providing direction, structure, and support for other team members. Can be demonstrated by several members. It does not imply formal authority.	Stewart & Barrick (2000) Dickinson & McIntyre (1997) Harris & Barnes-Farrell (1997) McIntyre & Salas (1995)
Coordination	The smooth synchronization and integration of interdependent activities.	Marks et al., (2001) Reid et al. (1999) Dickinson & McIntyre (1997) Harris & Barnes-Farrell (1997) Brannick et al. (1993) Fleishman & Zaccaro (1992)
Timing	General organization and pacing of activities such that tasks are completed according established parameters.	Militello et al., (1999) Fleishman & Zaccaro (1992)

Team processes	Definition / Description	Relevant sources
Mutual performance monitoring	Observing (at both the team and individual levels) the activities and performance in detection of errors and inefficiencies. This implies that team members will provide feedback and/or back-up behaviors if dictated. It also implies that each member is not only competent in one's own abilities, but also knowledgeable of the others' tasks as well.	Marks et al., (2001) Militello et al., (1999) Dickinson & McIntyre (1997) Harris & Barnes-Farrell (1997) McIntyre & Salas (1995) Fleishman & Zaccaro (1992)
Intra-team feedback	The giving, seeking and receiving of performance information among members. Implies that members show sufficient assertiveness to provide suggestions to others and a willingness to accept suggestions from others. Asynchronous feedback (i.e., team-self correction), has less of an impact than synchronous feedback.	Marks et al., (2001) Rasker et al., (2000) Dickinson & McIntyre (1997) Harris & Barnes-Farrell (1997) McIntyre & Salas (1995) Brannick et al. (1993) Fleishman & Zaccaro (1992)
Back-up Behaviors	Assisting other members when they are in need. Implies not only a willingness to do so, but also the ability to assist and the knowledge of when to assist (i.e., proper performance monitoring). Compensatory behaviors.	Marks et al., (2001) Dickinson & McIntyre (1997) Harris & Barnes-Farrell (1997) McIntyre & Salas (1995)
Motivational functions	Activities aimed at establishing objectives and performance norms and encouraging members to achieve those objectives.	Marks et al., (2001) Fleishman & Zaccaro (1992)
Cooperation	Quality of interpersonal relations. Behaviorally, it is the amount of conflict management or general encouragement of other members.	Marks et al., (2001) Militello et al., (1999) Brannick et al. (1993)

Table 2.

Summary of distributed collaboration effects.

Issue	Costs of issue	Benefits of issue	Potential Technology?
Less socio-emotional content in CM	Increase tendency for "flaming" Staff validity & Team informity decreased	Extraneous info filtered Hierarchical sensitivity increased Reduce psychological distance	Make use of other tools when appropriate MM – make use of many tools
Less communication units in CM	Reduction in loquacious members	Equalization of participation	
Poor quality of video	Used for "grounding" Visual non-verbal affects ratings of processes	Video not as necessary as thought; static images preferred	Assess what is needed Don't use video Improve video
No spontaneous encounters	No informal -discussion -feedback or -decision-making	Could this also be more productive?	Virtual work spaces (coffee pot on-line) Virtual "foyer"
No modeling	-Slower more tense socialization -Difficult to transition to in-group member	Are most engineers better at working alone? Are they not already skilled?	Newcomers collocated with experienced personnel
"Out-of-sight"	Team suffers when all members are not engaged	Could also be seen as filtering	e-assertiveness technology can increase awareness of quiet distributed members
Unrecognized conflicts	Go unchecked until boiling point. Disrupt team harmony	(Should note often due to misunderstandings)	Improve overall processes & relationships i.e., teambuilding & communication
Need common view of task	W/o shared view task is difficult even when collocated	With shared view, less interaction is needed	Information/knowledge warehouse
Travel	Fewer face-to-face meetings	Time is spared Travel costs reduced	Proper "tool bag" reduces the need

Note. CM = computer-mediated communication; MM = Multimedia communication (e.g., text, video, and audio); See text for descriptions of Hierarchical sensitivity, Staff validity and Team informity.

Figure Captions

Figure 1. The Team Effectiveness Model (TEM). Adapted from Tannenbaum, Beard and Salas (1992).

Figure 2. The Task Circumplex. Adapted from Hollingshead & McGrath (1995).

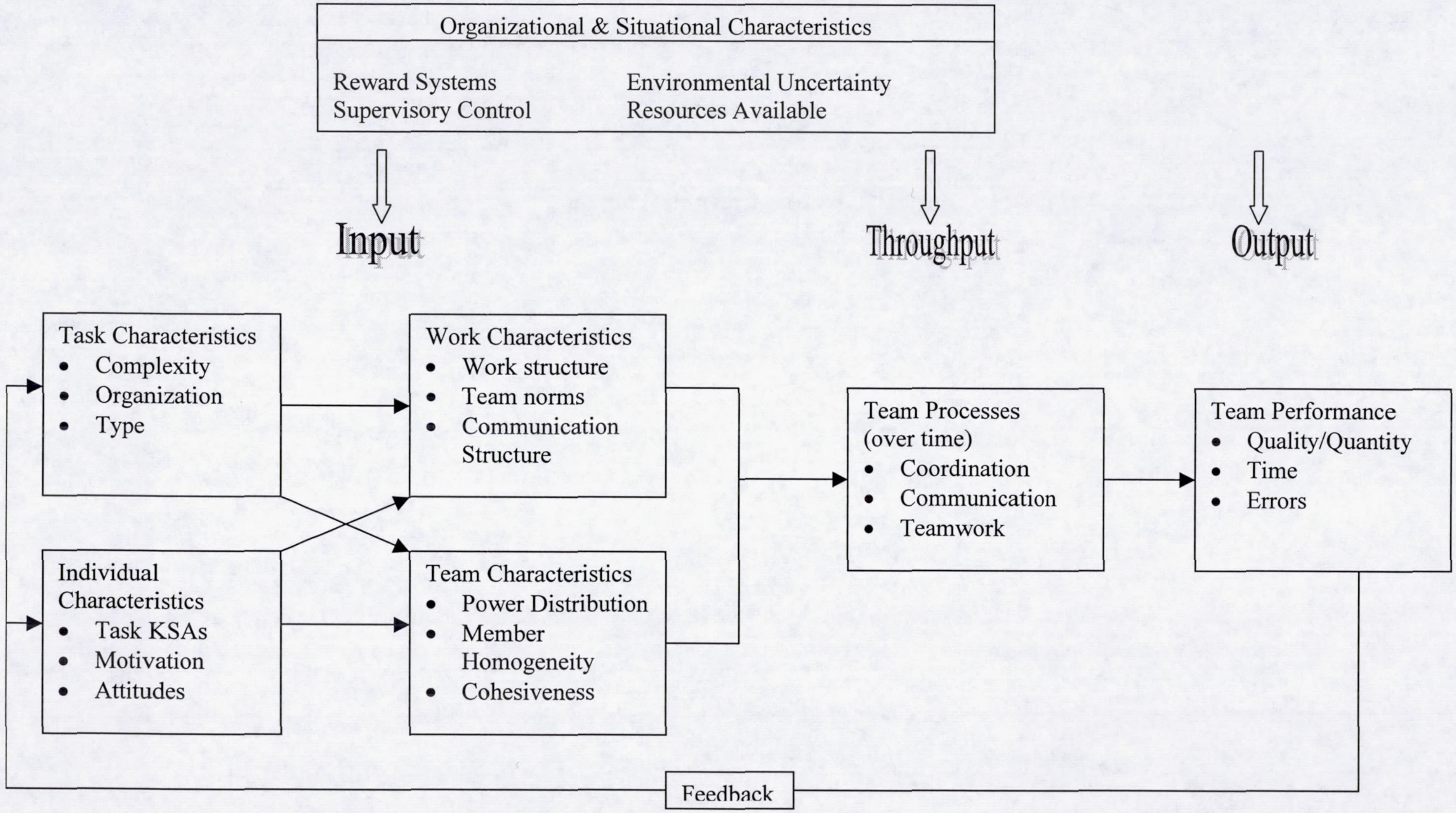

Organizational & Situational Characteristics
Reward Systems
Supervisory Control
Environmental Uncertainty
Resources Available
Input
Throughput
Output
Task Characteristics
• Complexity
• Organization
• Type
Work Characteristics
• Work structure
• Team norms
• Communication Structure
Individual Characteristics
• Task KSAs
• Motivation
• Attitudes
Team Characteristics
• Power Distribution
• Member Homogeneity
• Cohesiveness
Team Processes (over time)
• Coordination
• Communication
• Teamwork
Team Performance
• Quality/Quantity
• Time
• Errors
Feedback

Figure 1.

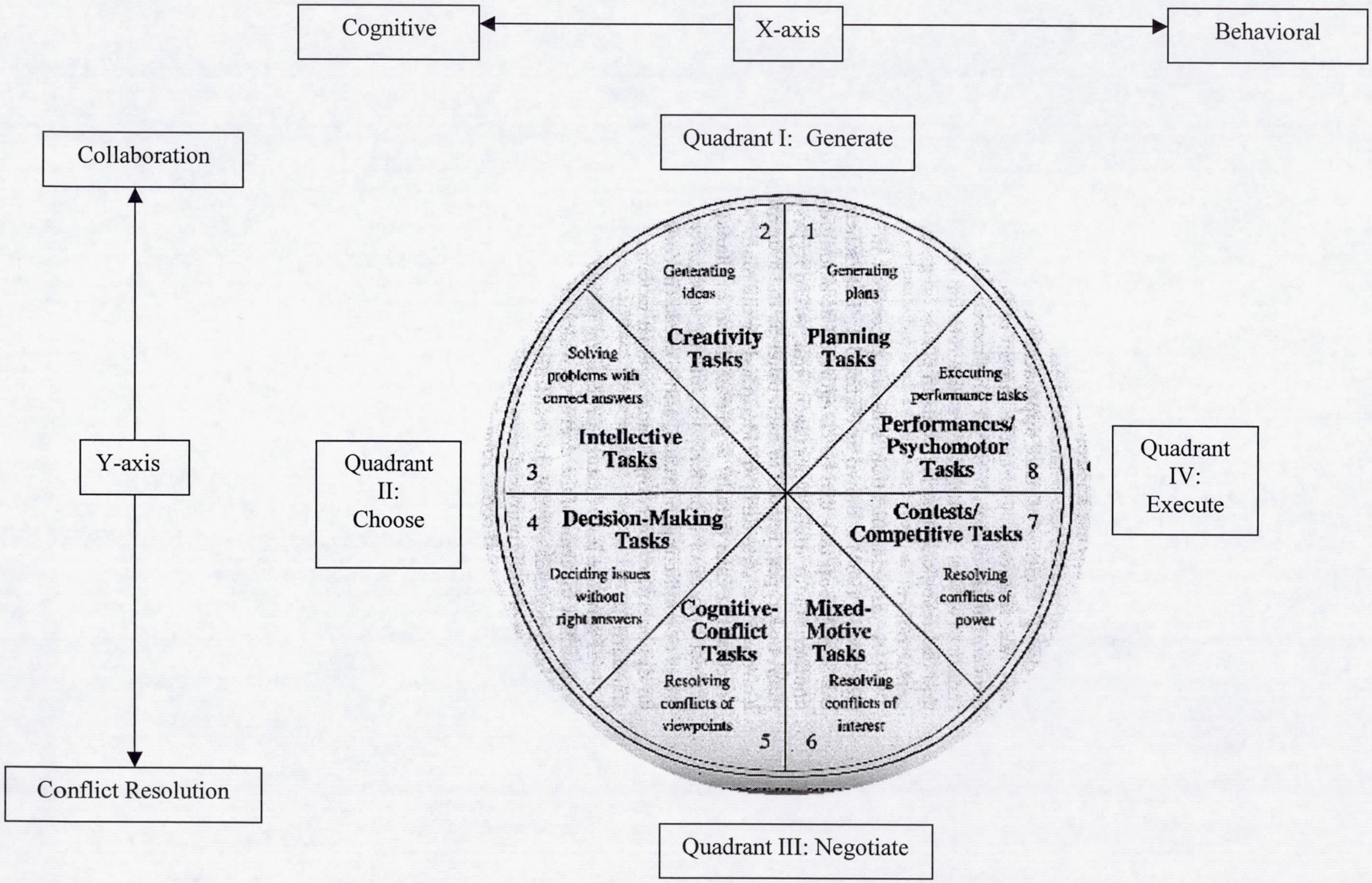

Cognitive
X-axis
Behavioral
Collaboration
Y-axis
Conflict Resolution
Quadrant I: Generate
Quadrant II: Choose
Quadrant III: Negotiate
Quadrant IV: Execute
1 Generating plans Planning Tasks
2 Generating ideas Creativity Tasks
3 Solving problems with correct answers Intellective Tasks
4 Decision-Making Tasks Deciding issues without right answers
5 Cognitive-Conflict Tasks Resolving conflicts of viewpoints
6 Mixed-Motive Tasks Resolving conflicts of interest
7 Contests/ Competitive Tasks Resolving conflicts of power
8 Executing performance tasks Performances/ Psychomotor Tasks

Figure 2

Annex B

Team Task Analysis of ISAT – Inter-center Systems Analysis Team

Team Task Analysis of ISAT – Inter-center Systems Analysis Team

During the August 2001 Workshop as viewed from LaRC

Table of Contents

ISAT – Overview

The Inter-center Systems Assessment Team (ISAT) is charged with performing advanced technology assessments on concept vehicles. The technology evaluations are used by the 2^{nd} Gen. program to make technology investment strategy decisions. The team has previously conducted these analyses in the Collaborative Engineering Center (CEC) at MSFC. Since the analysts that comprise the team are located at various NASA facilities (e.g., LaRC, ARC, JSC—see Figure 1), a goal exists to work in a distributed environment. Currently, the team meets for a week in the CEC to perform 15-16 analyses—approximately 4 per day. The task is largely sequential in nature meaning that the work flows unidirectionally from a given starting point. The ultimate goal of the ISAT team is to increase efficiency and work from the individual analysts workstation without the need for travel to the CEC at MSFC. The succeeding task analysis is based on documents and presentations obtained from RSTS, various informal interviews of RSTS members and ISAT members as well as observations of the activities that occurred during the weeklong workshop in August 2001 as observed from the LaRC location (activities occurred in various locales).

ISAT – Team Tasks

ISAT is comprised of various sub-teams representing various disciplines. Currently, the disciplines include vehicle closure (which includes weights and sizing experts that work with trajectory experts), safety and reliability, operations, and costs & economics. Each discipline has various analysis tools to perform the particular evaluations. A goal in the future is to include more discipline assessments for each concept vehicle to aid in the vehicle recommendations. Additional disciplines include structures & thermal, propulsion system, aerodynamics & control, avionics & power, and IVHM. The team recently performed a workshop in a semi-distributed environment, illustrated in Figure 1.

The flow of work is illustrated in Figure 2. Prior to these assessments, several activities have occurred, 1) the reference vehicle has been defined and validated, 2) the technology data have been collected, and 3) the technology data have been used to modify the reference vehicle models. Having these steps completed, the assessments may commence. Each step will be described in turn below. In the current situation using ADTT as a database management tool, between 1 and 3 different models are used per vehicle (i.e., HAVOC, INTROS, and CONSIZ). A decision is made at some point (it is not clear if this is a post hoc or a priori decision) as to which model to base the recommendations on. Each of these models is briefly discussed below. In diagram in Figure 2, the rows represent the various model assessments and the columns represent the various disciplines (e.g., weights & sizing, safety, economics, etc). The rows may be run concurrently, however the columns must be conducted sequentially. That is, the various models are independent of one another, but within the models, the flow of work is sequential. During the workshop, ISAT ran assessments using all three models for two vehicle cases and only the INTROS model for the final case. Each discipline is comprised of one or more analysts depending on the needs of the assessment.

Team Structure

The overall interdependence of the team task can be described as sequential, however as will be described below, the various sub-teams operate in a reciprocal manner. The overall team task is conjunctive (i.e., no one member has the capability to perform the total assessment—various members hold expertise in their disciplines and to provide the overall assessment, the members have to pool resources). Although, by being sequential, the individual sub-teams require minimal contact with each other. The team's assessments are ultimately used in a hierarchical fashion (i.e., management uses the reports generated to make a decision/ recommendation), however, the team and its sub-teams interact in a non-hierarchical manner. While the individuals work relatively autonomously, they are sanctioned by the sequential design and the time frames imposed by the assessment process.

ADTT

ADTT is a web-based database developed at ARC. ISAT members using ADTT are able to "download" the data necessary for their particular discipline assessments and "upload" or publish the results of their assessment back to

the central store. ADTT is used to manage the flow of the data and to assist in generating reports (as defined by specifications) for management and analyst use.

Each step in the process will be discussed in turn below, but the essentials of ADTT are this. ADTT is designed to require the ISAT discipline analysts to wait for upstream assessments to be completed before downstream analysts may obtain the needed data. The data is stored and used in extended mark up language (.xml) an industry standard. This enables the data to be utilized by multiple applications. The individual analysts obtain the needed data and process it with the appropriate assessment tools within Model Center.

Distribution

Figure 1 illustrates the overall distribution of the ISAT team during the August workshop. The assessments took place across three NASA facilities (ARC, MSFC & LaRC). The team was operating in a semi-distributed fashion, meaning that individuals of each of the sub-teams were collocated, but the sub-teams (disciplines) were dispersed. This proved beneficial given the novelty of working outside of the MSFC CEC.

The vehicle closure discipline was represented by 1 expert in CONSIZ working with a POST expert, 1 expert in INTROS also working closely with a POST expert (all located at LaRC) and 1 expert in HAVOC (this analyst was the only member at ARC). The safety & reliability discipline was represented by 1 expert also at LaRC. The 5 discipline experts at LaRC were closely observed for the duration of the workshop. Activities of the remaining ISAT team members had to be inferred or inquired about.

At MSFC, 2 disciplines were each comprised of several experts of distributed expertise. Operations involved 2 experts working closely at the same workstation (it is difficult to infer the need for these two people) via NROC. Finally, the costs & economics discipline involved the use of at least 4 workstations (1 executive, and 3 sub-divisions—NAFCOM, IEM-optimistic, IEM-pessimistic).

Pre-CEC activities

Much work is done in preparation of the collaborative engineering prior to team meetings. In particular, individual technologists must prepare the data for inputting in their respective models. Several activities have occurred prior to the collaborative engineering assessment phase. 1) the reference vehicle has been defined and validated, 2) the technology data have been collected, and 3) the technology data have been used to modify the reference vehicle models. It is not clear how much "teamwork" is required of the members during the pre-CEC activities.

Individual analyses

POST-CONSIZ

The POST_CONSIZ use case consists of 2 analysts working closely together (one POST analyst and one CONSIZ analyst). POST (Program to Optimize Simulated Trajectories) is program utilized for trajectory analysis. CONSIZ (CONfiguration SIZing) is a tool, which calculates weights and sizing data for analysis, conceptual design and preliminary design of launch vehicles. The analysts work individually on each tool, however the two need to come to agreement on the integration of the individual analyses. Thus, the two are always performed in tandem.

These analyses (must be mentioned together) can be performed concurrently with POST-INTROS & HAVOC, but must be completed before downstream analyses can occur. See figure 2. Therefore, the POST-CONSIZ experts have a reciprocal relationship with each other, a pooled relationship with other weights and sizing analysts and form the initial step in a sequential chain of other disciplines (i.e., safety, operations, costs & economics, etc.) for that particular model. Currently, the POST analyst and the CONSIZ analyst had to work "over each other's shoulder" on the same machine.

Although the analyses are cognitive tasks by their nature, the sequences of events detailing the POST_CONSIZ tasks would predominately fall within the *execute* quadrant of McGrath's circumplex (McGrath, 1984). More

specifically, they are executing performance tasks. Although, to some extent, a decision-making tasks occurs by the analysts in determining whether the data has converged. See Appendix A and Figure 3 for a description of the individual sequence of events performed by the sub-team. The checklist in the appendix represents the steps taken beginning with obtaining the data through publishing the data following analyses. The figure represents the analyses conducted while in possession of the data.

POST-INTROS

The POST-INTROS use case consists of 2 analysts working closely together (one POST analyst and one INTROS analyst). POST (Program to Optimize Simulated Trajectories) is program utilized for trajectory analysis. INTROS (INTegrated ROcket Sizing) is a tool which calculates weights and sizing data for analysis, conceptual design and preliminary design of launch vehicles. The analysts work individually on each tool, however the two need to come to agreement on the integration of the individual analyses. Thus, the two are always performed in tandem.

These analyses (must be mentioned together) can be performed concurrently with POST-CONSIZ & HAVOC, but must be completed before downstream analyses can occur. See figure 2. Therefore, the POST-INTROS experts have a reciprocal relationship with each other, a pooled relationship with other weights and sizing analysts and form the initial step in a sequential chain of other disciplines (i.e., safety, operations, costs & economics, etc.) for that particular model. Currently, the POST analyst and the INTROS analyst had to work "over each other's shoulder" on the same machine.

Although the analyses are cognitive tasks by their nature, the sequences of events detailing the POST_CONSIZ tasks would predominately fall within the *execute* quadrant of McGrath's circumplex (McGrath, 1984). More specifically, they are executing performance tasks. Although, to some extent, a decision-making task occurs by the analysts in determining whether the data has converged—this is represented by McGrath's *choose* quadrant. See Appendix B and Figure 4 for a description of the individual sequence of events performed by the sub-team. The checklist in the appendix represents the steps taken beginning with obtaining the data through publishing the data following analyses. The figure represents the analyses conducted while in possession of the data.

HAVOC

HAVOC (do not have the origin of this acronym) is a tool that can be performed by a single analyst to assess the trajectory *and* the weights and sizing similar to the above-mentioned models. This analysis was performed at ARC and was not physically observed.

Similar to INTROS and CONSIZ, this model begins with the HAVOC analysis and is sequential for downstream disciplines (i.e., safety, operations, costs & economics, etc.). It may also be run concurrently with INTROS and CONSIZ.

The checklist for this analyst (note only one individual in this task/cell) is found in appendix C. Since direct observations were not made, it must be inferred that the tasks of the HAVOC expert are similar to those of the other vehicle closure experts (i.e., trajectory and weights & sizing). Therefore, the sequences of events detailing the HAVOC tasks would predominately fall within the *execute* quadrant of McGrath's circumplex (McGrath, 1984). More specifically, they are executing performance tasks. Again, it must be inferred that a decision-making task of assessing convergence occurs.

Safety-reliability

The safety and reliability discipline is represented by analysts from SAIC (Science Applications International Corporation), an organization contracted to develop a safety assessment tool. During the workshop, only one user occupied this position.

Structurally, the safety analyst depends on upstream information to perform his (all analysts at LaRC during the workshop were male) task. Likewise, those disciplines downstream of the safety analyst depend on the output of the

safety assessment. The safety discipline must run the same analysis on all three models (i.e., CONSIZ, INTROS, and HAVOC). This is provided an a priori decision has not been made as to which model will be used. For one assessment during the workshop, only the INTROS model was used. When only one analyst is used, an inherent bottleneck occurs in the sequence. That is, safety cannot perform any analyses prior to the completion of the vehicle closure team, and then is expected to perform analyses on all models while others downstream are awaiting his output. This is illustrated in Figure 2. While many analysts work on the vehicle closure column (5 in all), only one performs the assessments in the safety column.

The activities are expressed in the checklist for the safety analysis in appendix D. Similar to the vehicle closure team, the analyses are cognitive tasks by their nature, but the sequences of events detailing the safety and reliability tasks would predominately fall within the *execute* quadrant of McGrath's circumplex (McGrath, 1984). More specifically, they are executing performance tasks.

COMET/ NROC

This discipline was not directly observed. It is inferred that the individual tasks are similar to those of the previously mentioned disciplines. The operations assessment (conducted via NROC) is represented by the operations column of Figure 2 and addresses ground and flight operations costs.

Appendix E displays the stepwise tasks performed by the analyst(s). Structurally, the operations discipline is sequentially interdependent with the other disciplines (i.e., see operations column of Figure 2.). It is not known whether 1 or more operators performed the analyses for this discipline. It is assumed that the operations discipline is similar to the safety discipline with respect to interdependence with others.

NAFCOM-R/IEM

This discipline was not physically observed. It is perhaps the most complicated of the disciplines. Has one workstation deemed the executive and then 3 separate stations for each sub-discipline (i.e., NAFCOM-costs; IEM pessimistic—economics; and, IEM optimistic-economics). IEM – (ISTP [Integrated Space Transportation Plan] Economics Model). NAFCOM tool predicts DDT&E (design, development, test and evaluation) and TFU (Theoretical first unit) cost estimates including the cost of subsystem and component hardware, system integration, scientific instruments and/or engine systems.

In the sequential chain, this discipline is last. It is dependent on "good" data from upstream sources. It is not clear how much interaction must occur between the sub-disciplines. This discipline is represented by the final column of Figure 2. The figure shows that the discipline is further sub-divided into the 3 sub-teams.

Subsequent actions

Reports

Management of the ISAT team generates reports and assesses the overall activities. Reports are also used by the members to (1) monitor their own activities – that is to quickly review their data, and (2) by members needing data from a discipline they are not expert. These reports can serve as team processes such as mutual performance monitoring.

Recommendations

Decisions are not made as to the feasibility of concept vehicles, but rather, recommendations are sent to 2nd Gen. Decisions are made as to which model best assesses the vehicle (i.e., HAVOC, POST-CONSIZ, POST-INTROS). These decisions may be made a priori or at some point during or after the assessments.

Sources

Data comes from – observations, checklists, internal documents such as .ppts, .docs etc.

Figure 1.

Figure 1. Semi-distribution of discipline analysts.

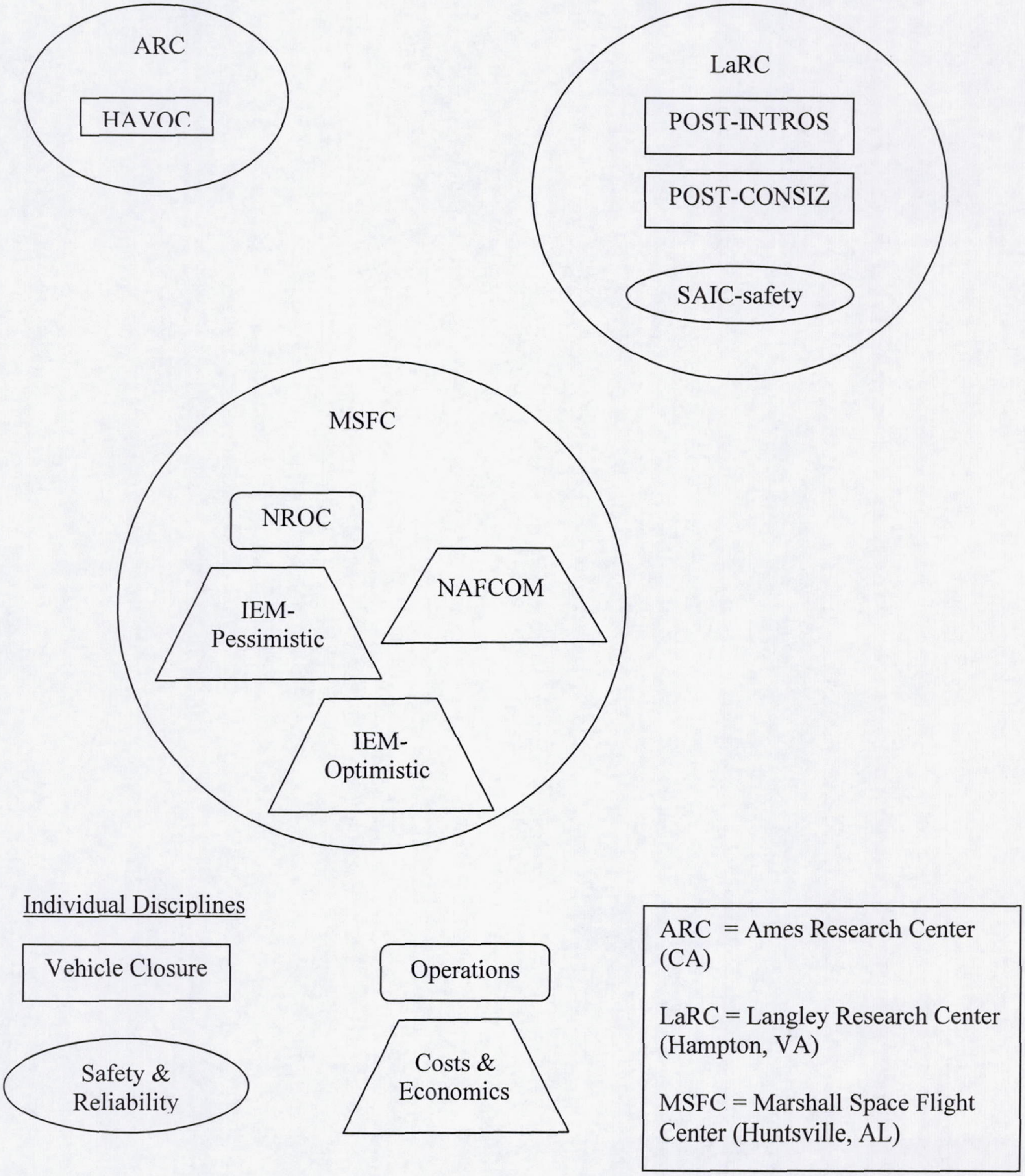


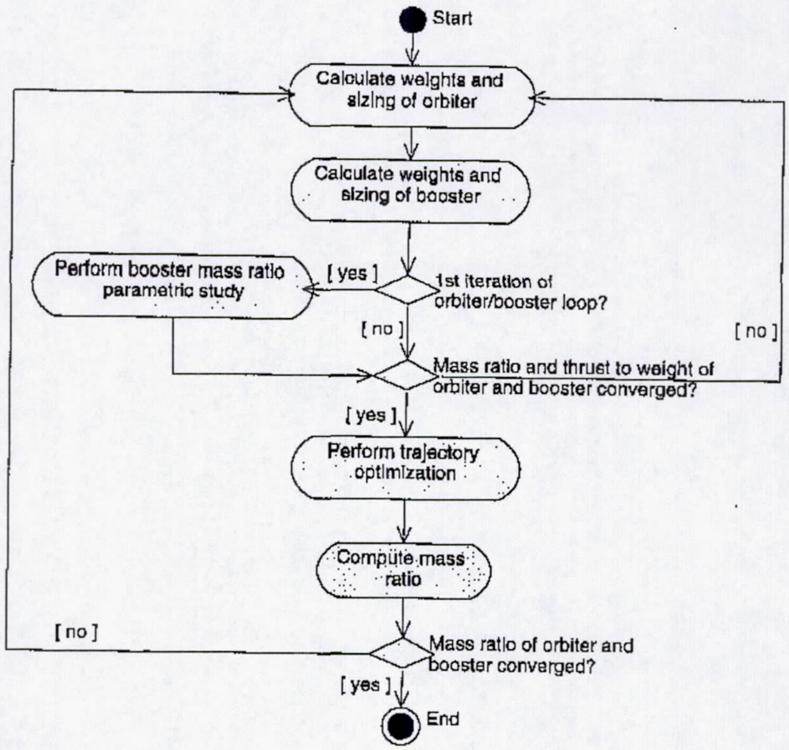
Figure 2.

<u>Figure 2.</u> Model of workflow as dictated by ADTT parameters. (Each double-bordered block represents a separate analysis)

<table>
<tr><th></th><th>Vehicle Closure</th><th>→</th><th>Safety & Reliability</th><th>→</th><th>Operations</th><th>→</th><th colspan="3">Cost & Economics</th></tr>
<tr><td rowspan="6">Independent Models</td><td>POST</td><td rowspan="2">→</td><td rowspan="2">POST-CONSIZ model using SAIC safety assessment</td><td rowspan="2">→</td><td rowspan="2">POST-CONSIZ model using NROC</td><td rowspan="2">→</td><td colspan="3">POST-CONSIZ model</td></tr>
<tr><td>CONSIZ</td><td>NAFCOM</td><td>IEM-opti</td><td>IEM-pess</td></tr>
<tr><td>POST</td><td rowspan="2">→</td><td rowspan="2">POST-INTROS model using SAIC safety assessment</td><td rowspan="2">→</td><td rowspan="2">POST-INTROS model using NROC</td><td rowspan="2">→</td><td colspan="3">POST-INTROS model</td></tr>
<tr><td>INTROS</td><td>NAFCOM</td><td>IEM-opti</td><td>IEM-pess</td></tr>
<tr><td rowspan="2">HAVOC</td><td rowspan="2">→</td><td rowspan="2">HAVOC using SAIC safety assessment</td><td rowspan="2">→</td><td rowspan="2">HAVOC using NROC</td><td rowspan="2">→</td><td colspan="3">HAVOC</td></tr>
<tr><td>NAFCOM</td><td>IEM-opti</td><td>IEM-pess</td></tr>
</table>

Figure 3.

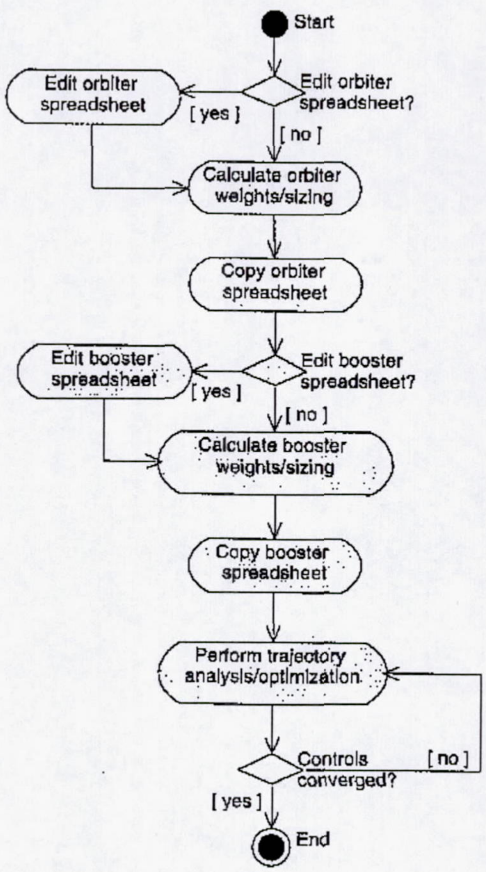
Figure 3. Diagram of CONSIZ process. (I am waiting for Andrea Salas to send the digital files of this figure and the next– I simply scanned this one in low-res)



Activity Diagram - Analyze Performance (Consiz)

Figure 4

Figure 4. Diagram of INTROS process.



Activity Diagram   Analyze Performance (Intros)

Appendix A

POST-CONSIZ checklist for using ADTT

1. **Log onto the website.**
    a. Enter the ADTT website at http://www.nas.nasa.gov/adttWeb.
    b. Login to your account by typing your login id and password and clicking on **SUBMIT**.
    c. Select the **ISATProject** and click on **GO**.
2. **Download the ModelCenter model file from the ADTT database onto your machine.**
    a. Expand the Object Navigation Tree on the left of the page until the desired concept appears. This will be Bimese, Shuttle or Adv. Bimese
    b. Click on the desired Concept in the Object Navigation tree.
    c. Click on the **Studies** tab in the Content Area on the right.
    d. Click on the **VIEW MATRIX** link.
    e. Select the desired Mission and click **DISPLAY**.
    f. Check to see that all upstream analyses (i.e. all cells to the left of the Post-Consiz~VehicleClosure column) are either **Not Required** or **Complete**. If an upstream analysis is **Required** or **In Progress**, you cannot proceed any further.
    g. Click on the white cell marked **REQUIRED** in the Post-Consiz ~VehicleClosure column, in the desired Vehicle row. Click this cell until it turns yellow.
    h. Click on the **Set Cell to In-Progress** button.
    i. The Cell will appear yellow and a link to the ModelCenter file containing Post-Consiz will be present. Right-click on this link and select '**Save Target As…**'
    j. Save the ModelCenter file onto your local machine. Be sure to select the 'All Files' file type and provide the .pxc file extension.
3. **Run your application locally.**
    a. Open Model Center and load the ModelCenter (.pxc) file you just downloaded.
    b. If a template file for CONSIZ needs to be changed, enter the new template file name next to the **templateFile** variable and make sure to **reinitialize** the component by right-clicking the component and click the "Reload Templates" button.
    c. A trajectory file is generated after a POST run. A plotting tool can be launched within Model Center to view the trajectory.
    d. Once the analysis is complete, be sure to run the dataDictOUT component at the end of your POST-INTROS Model. Save your Model File.
4. **Update the ADTT database by uploading your completed ModelCenter file.**
    a. If you have logged out of the ADTT system, log back in.
    b. In your browser, expand the Object Navigation Tree on the left of the page until the desired concept appears. This will be Bimese, Shuttle or Adv. Bimese
    c. Click on the desired Concept in the Object Navigation tree.
    d. Click on the **Studies** tab in the Content Area on the right.
    e. Click on the **VIEW MATRIX** link.
    f. Select the desired Mission and click **DISPLAY**.
    g. Click on the **Check In** link in the cell you wish to upload to. This should be the cell representing the Post-Consiz ~VehicleClosure column for the vehicle you are about to upload to. Clicking the **Check In** link will pop up a window in the upper left of your screen.
    h. Browse your computer for the name of the ModelCenter file to upload. Type in a short comment. Click on **Check-in ModelCenter File**. Wait until the pop-up window says the upload was successful; it may take a while.
    i. Close the pop-up window when done.
5. **Refresh the Run Matrix.**
    a. Click the '**Refresh Matrix**' Button
    b. A link to the raw Post-Consiz data files will appear in the Completed cell

Appendix B

POST-INTROS checklist for using ADTT

1. **Log onto the website.**
   a. Enter the ADTT website at http://www.nas.nasa.gov/adttWeb.
   b. Login to your account by typing your login id and password and clicking on **SUBMIT**.
   c. Select the **ISATProject** and click on **GO**.
2. **Download the ModelCenter model file from the ADTT database onto your machine.**
   a. Expand the Object Navigation Tree on the left of the page until the desired concept appears. This will be Bimese, Shuttle or Adv. Bimese
   b. Click on the desired Concept in the Object Navigation tree.
   c. Click on the **Studies** tab in the Content Area on the right.
   d. Click on the **VIEW MATRIX** link.
   e. Select the desired Mission and click **DISPLAY**.
   f. Check to see that all upstream analyses (i.e. all cells to the left of the Post-Intros~VehicleClosure column) are either **Not Required** or **Complete**. If an upstream analysis is **Required** or **In Progress**, you cannot proceed any further.
   g. Click on the white cell marked **REQUIRED** in the Post-Intros~VehicleClosure column, in the desired Vehicle row. Click this cell until it turns yellow.
   h. Click on the **Set Cell to In-Progress** button.
   i. The Cell will appear yellow and a link to the ModelCenter file containing Post-Intros will be present. Right-click on this link and select **'Save Target As...'**
   j. Save the ModelCenter file onto your local machine. Be sure to select the 'All Files' file type and provide the .pxc file extension.
3. **Run your application locally.**
   a. Open ModelCenter and load the ModelCenter (.pxc) file you just downloaded.
   b. To run INTROS in interactive mode, make sure that the **userInTheLoop** flag for that component is set to **true.**
   c. If a template file for INTROS needs to be changed, enter the new template file name next to the **templateFile** variable and make sure to **reinitialize** the component by right-clicking the component and click the "reinitialize" button.
   d. When running INTROS in interactive mode, **DO NOT** close the EXCEL window. Always click the "OK" button in the pop up dialog box when finished.
   e. Try to modify input values in Model Center. If wrapped variables are changed after running interactive mode, make sure to right-click the component and click the "Reload Input Values" button. **DO NOT** modify any input variables that are linked from upstream components. Linked variables can not be reloaded.
   f. A trajectory file is generated after a POST run. A plotting tool can be launched within Model Center to view the trajectory.
   g. Once the analysis is complete, be sure to run the dataDictOUT component at the end of your POST-INTROS Model. Save your Model File.
4. **Update the ADTT database by uploading your completed ModelCenter file.**
   a. If you have logged out of the ADTT system, log back in.
   b. In your browser, expand the Object Navigation Tree on the left of the page until the desired concept appears. This will be Bimese, Shuttle or Adv. Bimese
   c. Click on the desired Concept in the Object Navigation tree.
   d. Click on the **Studies** tab in the Content Area on the right.
   e. Click on the **VIEW MATRIX** link.
   f. Select the desired Mission and click **DISPLAY**.
   g. Click on the **Check In** link in the cell you wish to upload to. This should be the cell representing the Post-Intros~VehicleClosure column for the vehicle you are about to upload to. Clicking the **Check In** link will pop up a window in the upper left of your screen.

h. Browse your computer for the name of the ModelCenter file to upload. Type in a short comment. Click on **Check-in ModelCenter File**. Wait until the pop-up window says the upload was successful; it may take a while.
i. Close the pop-up window when done.

5. **Refresh the Run Matrix.**
   a. Click the '**Refresh Matrix**' Button
   b. A link to the raw Post-Intros data files will appear in the Completed cell

Appendix C

HAVOC checklist for using ADTT

1. Log onto the website.
    a. Enter the ADTT website at http://www.nas.nasa.gov/adttWeb.
    b. Login to your account by typing your login id and password and clicking on SUBMIT.
    c. Select the ISATProject and click on GO.
2. Download the ModelCenter model file from the ADTT database onto your machine.
    a. Expand the Object Navigation Tree on the left of the page until the desired concept appears. This will be Bimese, Shuttle or Adv. Bimese
    b. Click on the desired Concept in the Object Navigation tree.
    c. Click on the Studies tab in the Content Area on the right.
    d. Click on the VIEW MATRIX link.
    e. Select the desired Mission and click DISPLAY.
    f. Check to see that all upstream analyses (i.e. all cells to the left of the HAVOC~VehicleClosure column) are either Not Required or Complete. If an upstream analysis is Required or In Progress, you cannot proceed any further.
    g. Click on the white cell marked REQUIRED in the HAVOC~VehicleClosure column, in the desired Vehicle row. Click this cell until it turns yellow.
    h. Click on the Set Cell to In-Progress button.
    i. The Cell will appear yellow and a link to the ModelCenter file containing HAVOC will be present. Right-click on this link and select 'Save Target As…'
    j. Save the ModelCenter file onto your local machine. Be sure to select the 'All Files' file type and provide the .pxc file extension.
3. Run your application locally.
    a. Open ModelCenter and load the ModelCenter (.pxc) file you just downloaded.
    b. If necessary, load the desired xyz files into the uploadXYZ component in the Model.
    c. If necessary, load the desired HAVOC input file(s) into the appropriate HAVOC components.
    d. Run Havoc by clicking the green run icon in the upper left of HAVOC component.
    e. Once the analysis is complete, be sure to run the dataDictOUT component at the end of your Havoc Model.
    f. Save your Model File.
4. Update the ADTT database by uploading your completed ModelCenter file.
    a. If you have logged out of the ADTT system, log back in.
    b. In your browser, expand the Object Navigation Tree on the left of the page until the desired concept appears. This will be Bimese, Shuttle or Adv. Bimese
    c. Click on the desired Concept in the Object Navigation tree.
    d. Click on the Studies tab in the Content Area on the right.
    e. Click on the VIEW MATRIX link.
    f. Select the desired Mission and click DISPLAY.
    g. Click on the Check In link in the cell you wish to upload to. This should be the cell representing the HAVOC~VehicleClosure column for the vehicle you are about to upload to. Clicking the Check In link will pop up a window in the upper left of your screen.
    h. Browse your computer for the name of the ModelCenter file to upload. Type in a short comment. Click on Check-in ModelCenter File. Wait until the pop-up window says the upload was successful; it may take a while.
    i. Close the pop-up window when done.
5. Refresh the Run Matrix.
    a. Click the 'Refresh Matrix' Button
    b. A link to the raw HAVOC data files will appear in the Completed cell

Appendix D

SAIC safety checklist for using ADTT

1. **Log onto the website.**
    a. Enter the ADTT website at http://www.nas.nasa.gov/adttWeb.
    b. Login to your account by typing your login id and password and clicking on **SUBMIT**.
    c. Select the **ISATProject** and click on **GO**.
2. Download the ModelCenter model file from the ADTT database onto your machine.
    a. Expand the Object Navigation Tree on the left of the page until the desired concept appears. This will be Bimese, Shuttle or Adv. Bimese
    b. Click on the desired Concept in the Object Navigation tree.
    c. Click on the **Studies** tab in the Content Area on the right.
    d. Click on the **VIEW MATRIX** link.
    e. Select the desired Mission and click **DISPLAY**.
    f. Check to see that all upstream analyses (i.e. all cells to the left of the SAIC~Safety column) are either **Not Required** or **Complete**. If an upstream analysis is **Required** or **In Progress**, you cannot proceed any further.
    g. Click on the white cell marked **REQUIRED** in the SAIC~Safety column, in the desired Vehicle row. Click this cell until it turns yellow.
    h. Click on the **Set Cell to In-Progress** button.
    i. The Cell will appear yellow and a link to the ModelCenter file containing the SAIC safety tool will be present. Right-click on this link and select '**Save Target As…**'
    j. Save the ModelCenter file onto your local machine. Be sure to select the 'All Files' file type and provide the .pxc file extension.
    k. You do not need to download the DataDictionary as the Ops group has done that for you.
3. Run your application locally.
    a. Open ModelCenter and load the .pxc file you just downloaded.
    b. Select and set the appropriate inputs for the component that you are going to run from those exposed within the component in ModelCenter.
        i. ModelCenter will automatically load values for the following variables:
            1. Launch Vehicle Type
            2. Case Name
            3. Number of Booster Engines
            4. Number of Orbiter Engines
            5. Booster Fuselage Area
            6. Orbiter Fuselage Area
            7. Booster Wing Area
            8. Orbiter Wing Area
            9. Booster Body Flap Area
            10. Orbiter Body Flap Area
            11. Booster Control Surface
            12. Orbiter Control Surface
            13. Booster Power Level
            14. Orbiter Power Level
        ii. The Safety Analyst running the component should review the following variables and update them to match the current case (drop down boxes provide a list of choices where appropriate):
            1. Booster Engine Type
            2. Orbiter Engine Type
            3. Crew Transfer Vehicle
            4. Auxiliary Power Type
            5. OMS Propellant Type
            6. RCS Propellant Type
            7. Advanced Structures
            8. Advanced Undercarriage
            9. Blanket TPS
            10. CMC Control Surfaces

11. Composite Tanks
12. Densified Propellants
13. Electromechanical Actuators
14. Power Management and Distribution
15. IVHM
16. PEM Fuel Cells
17. Rapid Turnaround TPS

c. Run the desired component. Average runtime is 90 seconds.
d. Once all analysis is complete, you need to run the dataDictOut component. This is done by first using the right mouse click on the dataDictOut component icon within the main component view window, and selecting the Reload Templates from the menu. Next hit yes to update the variables and then run the component.

4. Update the ADTT database by uploading your completed ModelCenter file.

a. If you have logged out of the ADTT system, log back in.
b. In your browser, expand the Object Navigation Tree on the left of the page until the desired concept appears. This will be Bimese, Shuttle or Adv. Bimese
c. Click on the desired Concept in the Object Navigation tree.
d. Click on the Studies tab in the Content Area on the right.
e. Click on the VIEW MATRIX link.
f. Select the desired Mission and click DISPLAY.
g. Click on the Check In link in the cell you wish to upload to. This should be the cell representing the SAIC~Safety column for the vehicle you are about to upload to. Clicking the Check In link will pop up a window in the upper left of your screen.
h. Browse your computer for the name of the ModelCenter file to upload. Type in a short comment. Click on Check-in ModelCenter File. Wait until the pop-up window says the upload was successful; it may take a while.
i. Close the pop-up window when done.

5. Refresh the Run Matrix.

a. Click the 'Refresh Matrix' Button
b. A link to the raw SAIC~Safety data files will appear in the Completed cell

Appendix E

NROC checklist for using ADTT

1. **Log onto the website.**
    a. Enter the ADTT website at http://www.nas.nasa.gov/adttWeb.
    b. Login to your account by typing your login id and password and clicking on **SUBMIT**.
    c. Select the **ISATProject** and click on **GO**.
2. **Download the ModelCenter model file from the ADTT database onto your machine.**
    a. Expand the Object Navigation Tree until the desired concept appears. This will be Bimese, Shuttle or Adv. Bimese
    b. Click on the desired Concept in the Object Navigation tree.
    c. Click on the **Studies** tab in the Content Area on the right.
    d. Click on the **VIEW MATRIX** link.
    e. Select the desired Mission and click **DISPLAY**.
    f. Check to see that all upstream analyses (i.e. all cells to the left of the COMET~Operations column) are either **Not Required** or **Complete**. If an upstream analysis is **Required** or **In Progress**, you cannot proceed any further.
    g. Click on the white cell marked **REQUIRED** in the COMET~Operations column, in the desired Vehicle row. Click this cell until it turns yellow.
    h. Click on the **User Save Checked-out Cell** button.
    i. Refresh the table by repeating steps 1-c and 1-d above. The **In Progress** cell should now contain a link to the appropriate ModelCenter and XML data dictionary files.
    j. Download the ModelCenter and XML data dictionary files to your local machine by right-clicking on the links and saving the files to the locations of your choice on your local machine.
3. **Run your application locally.**
    a. Open ModelCenter and load the .pxc file you just downloaded.
    b. Load the XML data dictionary into the model you just opened by first exposing the first level of variables under the dataDictIn component within the component list on the left hand side of your ModelCenter view. Right click the rawInput variable and select "load from file" from the menu. Browse and select the XML data dictionary file that you just downloaded.
    c. Run the dataDictIn component.
    d. Select and set the appropriate NROC inputs from those exposed within the component in ModelCenter.
    e. Run the NROC component. If the component is run interactively set the appropriate input parameter (for example in the NoFeeTo sheet) to NROC.
    f. If the NROC sheet was run in interactive mode finish the NROC run by hitting the OK button on the vbScript dialog (DO NOT EXIT DIRECTLY FROM EXCEL).
    g. Save the ModelCenter model file to the same or new file name.
4. Update the ADTT database by uploading your completed ModelCenter file.
    a. If you have logged out of the ADTT system, log back in.
    b. In your browser, expand the Object Navigation Tree on the left of the page until the desired concept appears. This will be Bimese, Shuttle or Adv. Bimese
    c. Click on the desired Concept in the Object Navigation tree.
    d. Click on the **Studies** tab in the Content Area on the right.
    e. Click on the **VIEW MATRIX** link.
    f. Select the desired Mission and click **DISPLAY**.
    g. Click on the **Check In** link in the cell you wish to upload to. This should be the cell representing the COMET~Operations column for the vehicle you are about to upload to. Clicking the **Check In** link will pop up a window in the upper left of your screen.
    h. Browse your computer for the name of the ModelCenter file to upload. Type in a short comment. Click on **Check-in ModelCenter File**. Wait until the pop-up window says the upload was successful; it may take a while.
    i. Close the pop-up window when done.
5. Refresh the Run Matrix.
    a. Click the '**Refresh Matrix**' Button
    b. A link to the raw COMET data files will appear in the Completed cell

Appendix F

NAFCOM-R/IEM checklist for using ADTT

1. **Log onto the website.**
    a. Enter the ADTT website at http://www.nas.nasa.gov/adttWeb.
    b. Login to your account by typing your login id and password and clicking on **SUBMIT**.
    c. Select the **ISATProject** and click on **GO**.
2. **Download the ModelCenter model file from the ADTT database onto your machine.**
    a. Expand the Object Navigation Tree on the left of the page until the desired concept appears. This will be Bimese, Shuttle or Adv. Bimese
    b. Click on the desired Concept in the Object Navigation tree.
    c. Click on the **Studies** tab in the Content Area on the right.
    d. Click on the **VIEW MATRIX** link.
    e. Select the desired Mission and click **DISPLAY**.
    f. Check to see that all upstream analyses (i.e. all cells to the left of the NAFCOM-IEM~Cost-Econ column) are either **Not Required** or **Complete**. If an upstream analysis is **Required** or **In Progress**, you cannot proceed any further.
    g. Click on the white cell marked **REQUIRED** in the NAFCOM-IEM~Cost-Econ column, in the desired Vehicle row. Click this cell until it turns yellow.
    h. Click on the **Set Cell to In-Progress** button.
    i. The Cell will appear yellow and a link to the ModelCenter file containing NAFCOM-IEM will be present. Right-click on this link and select '**Save Target As...**'
    j. Save the ModelCenter file onto your local machine. Be sure to select the 'All Files' file type and provide the .pxc file extension.
    k. You do not need to download the DataDictionary as the Ops group has done that for you.
3. Run your application locally.
    a. Open ModelCenter and load the .pxc file you just downloaded.
    b. Select and set the appropriate inputs for the component that you are going to run from those exposed within the component in ModelCenter.
    c. Run the desired component. In some cases you may have to wait for an upstream tool within the model to be run first.
    d. If the component is run interactively set the appropriate input parameters.
    e. If the component was run in interactive mode, finish the excel instance by hitting the OK button on the vbScript dialog (DO NOT EXIT DIRECTLY FROM EXCEL).
    f. Once all analysis is complete, you need to run the dataDictOut component. This is done by first using the right mouse click on the dataDictOut component icon within the main component view window, and selecting the Reload Templates from the menu. Next hit yes to update the variables and then run the component.
4. Update the ADTT database by uploading your completed ModelCenter file.
    a. If you have logged out of the ADTT system, log back in.
    b. In your browser, expand the Object Navigation Tree on the left of the page until the desired concept appears. This will be Bimese, Shuttle or Adv. Bimese
    c. Click on the desired Concept in the Object Navigation tree.
    d. Click on the **Studies** tab in the Content Area on the right.
    e. Click on the **VIEW MATRIX** link.
    f. Select the desired Mission and click **DISPLAY**.
    g. Click on the **Check In** link in the cell you wish to upload to. This should be the cell representing the NAFCOM-IEM~Cost-Econ column for the vehicle you are about to upload to. Clicking the **Check In** link will pop up a window in the upper left of your screen.
    h. Browse your computer for the name of the ModelCenter file to upload. Type in a short comment. Click on **Check-in ModelCenter File**. Wait until the pop-up window says the upload was successful; it may take a while.
    i. Close the pop-up window when done.
5. Refresh the Run Matrix.
    a. Click the '**Refresh Matrix**' Button
    b. A link to the raw NAFCOM-IEM data files will appear in the Completed cell

Annex C

Development and Assessment of an Engineering Team Process Model in a Distributed Collaborative Environment: The Case of ISAT

Development and Assessment of an Engineering Team Process Model in a Distributed Collaborative Environment: The Case of ISAT

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Executive Summary

Guided by a literature review on team processes from several domains (e.g., organizational and human factors psychology, and engineering management), a general model of team processes was developed. An engineering task analysis of a specific engineering team (Inter-center Systems Analysis Team of the National Aeronautics & Space Administration – ISAT) was used to develop an engineering specific model of team processes. The model (see figure 5, pg.11) includes the following processes relevant to engineering teams.

- Communication
- Mutual Performance Monitoring
- Coordination
- Intra-team Feedback

Measures were given to the ISAT members following a November workshop. The ISAT members scored themselves rather highly on two of the processes (i.e., communication & coordination) as well as in performance. Table 1 (page 15) shows those results. The survey demonstrated that the members do not agree on the extent of monitoring and feedback that occurs within the team. This cross-sectional observation indicates that the team processes of monitoring and feedback may be adversely affected by geographic distribution. Further enhancements of collaborative technology for distributed engineering should consider the impact of monitoring and feedback on team performance and make appropriate accommodations (e.g., automate monitoring of data, automate report generation).

Introduction

In a comprehensive review of the teamwork literatures, including organizational psychology, human factors psychology and engineering management, Fletcher and Major (2001) reported the existence of 12 conceptually distinct processes relevant to team effectiveness in general – each empirically supported in the literature. They also noted a host of moderators (e.g., task, team and individual characteristics) influencing the salience of each of the processes for different teams. That is, not all 12 processes are relevant for all teams at all times given team composition and characteristics. Recent advances in technology have allowed teams to work while the members are geographically dispersed, yet little is known about the effects of such dispersion on these team processes. Using a task analysis of a particular engineering team (i.e., Inter-center Systems Analysis Team of the National Aeronautics & Space Administration – ISAT) during workshops conducted in August 2001, an engineering process model was developed. Measures of team process were taken in a subsequent workshop of ISAT in November 2001. This report focuses on the development and validation of the engineering team process model in distributed collaborative environments.

Engineering Process Model

The general team process model depicted in Figure 1 is used to illustrate the role of interdependence and team processes on a team's performance. The model is generalizable to teams found in a variety of settings (e.g., sports teams, engineering teams, cockpit crews, etc.). Another model implicitly guiding the current discussion is depicted in Figure 2. The team process improvement model demonstrates a cycle of team assessment.

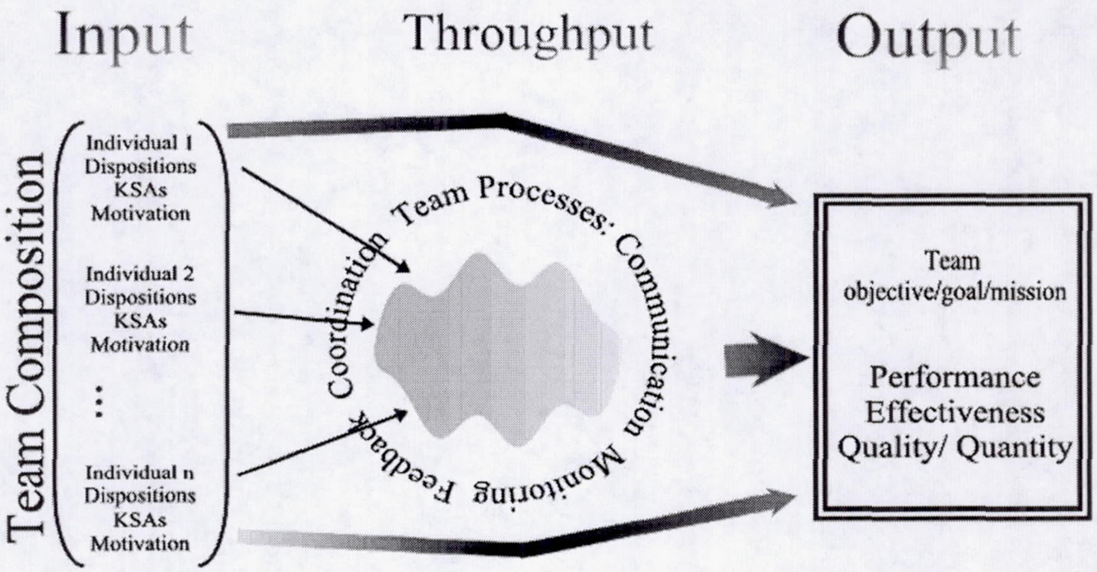

Figure 1. The general team process model.

A team must understand who is considered part of the team, what they do (and who relies on whom) and how they should best collaborate (i.e., teamwork behaviors that facilitate the necessary interactions). Finally, the model depicts a continuous cycle of implementation of the processes (e.g., through measurement and training). Through assessment of team behaviors/processes, one can determine if training is needed or if infrastructure changes would better accommodate the team. When any changes occur within the team or in the team's context (e.g., organizational constraints, technological implementation), then the assessment cycle should begin anew. That is, if the team's composition changes, or if the team task is altered, then another assessment should be undertaken.

A similar approach was taken in an assessment of ISAT. A task analysis of ISAT in a semi-distributed environment (Fletcher, 2001b) revealed that the individual sub-units (i.e., assessment disciplines) were largely sequentially interdependent. Figure 3 depicts

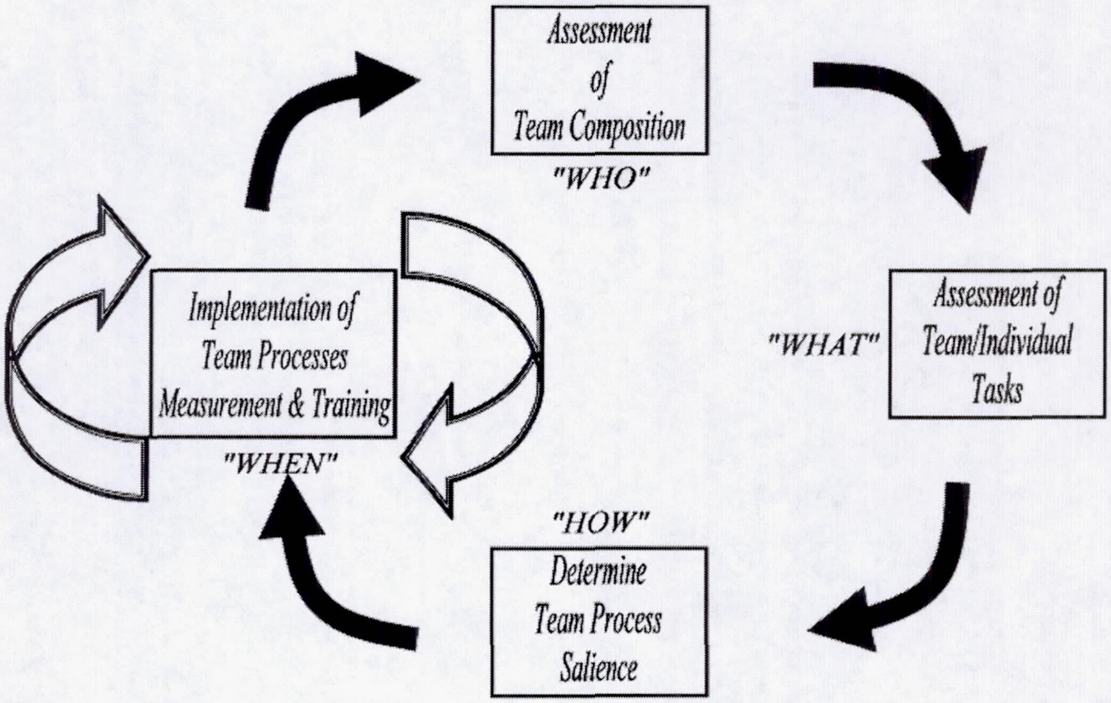

Figure 2. Team Process Improvement Model.

the general flow of work for each analysis and therefore the nature of the interdependence. Following the implementation of Product Data Management (PDM), several of the disciplines became parallel in nature. That is, the overall task remained sequential, starting with vehicle closure and ending with an economics assessment, but the newly structured team allows three disciplines to work simultaneously and independently for a particular assessment. Figure 4 depicts the new arrangement. This new work structure alleviates some of the interdependence among the disciplines (e.g., NAFCOM no longer 'waits' for FIRST to be completed before beginning its phase of the assessment). This being said, team processes that were salient before are expected to remain important to team performance and effectiveness.

General Team Process Model

The general team process model depicted in Figure 1 is an input – throughput – output model. Inputs include all contributions of the individual units that compose the team. These individual units may be smaller sub-units (i.e., side-bars, smaller teams, etc.) or individual team members. Each possesses a set of dispositions, knowledge, skills and abilities (KSAs), and level of motivation to perform the team task (Fletcher & Major, 2001). The output of the model represents the team's accomplishments (i.e., performance effectiveness both in terms of quality and quantity of output). This output is determined by the inputs, but partially mediated by the throughput variables. In the model, if individuals can contribute to the team outcome without the interaction of others (i.e., little interdependence) then team processes are less relevant to the team's performance. However, if interdependence exists, then team processes are important in influencing team effectiveness. By determining where the interdependencies among team members exist and applying the team processes that can best facilitate the team, performance can be enhanced.

ISAT Model of Team Processes

A first step in determining the influence of team processes and how they might be inhibited is to assess the team's interdependencies (i.e., where members rely on and interact with other members). The arrows in Figure 3 (i.e., ISAT in August – prior to PDM implementation) not only represent the flow of work for the ISAT team, they also indicate interactions among the disciplines (i.e., subunits). The boxes in Figure 3 (i.e., POST-CONSIZ, FIRST, NROC, etc.) represent the tools associated with a particular sub-unit. The members may not directly interact with another member (e.g., the FIRST user

	Vehicle Closure	➔	Safety & Reliability	➔	Operations	➔	Cost & Economics		
Independent Models	POST CONSIZ	➔	FIRST	➔	NROC	➔	NAFCOM	IEM-opti	IEM-pess
	POST INTROS	➔	FIRST	➔	NROC	➔	NAFCOM	IEM-opti	IEM-pess
	HAVOC	➔	FIRST	➔	NROC	➔	NAFCOM	IEM-opti	IEM-pess

Figure 3. Collaborative engineering and task interdependence: the ISAT case (August, 2001).

POST – CONSIZ		→	NROC	→		
	→	→	FIRST	→	→	IEM
		→	NAFCOM	→		
POST – INTROS		→	NROC	→		
	→	→	FIRST	→	→	IEM
		→	NAFCOM	→		
		→	NROC	→		
HAVOC	→	→	FIRST	→	→	IEM
		→	NAFCOM	→		

Figure 4. Revised ISAT interdependence model – parallel disciplines (November, 2001).

may not communicate directly with the HAVOC user), but they are dependent on each other. Specifically in a sequential fashion – those downstream must wait for and depend on the accuracy of information to be processed by those upstream. The revised interdependencies model, Figure 4, shows a more parallel distribution, but the interdependencies remain largely sequential (e.g., the FIRST user must wait on the POST-CONSIZ user, the IEM user must wait and depends on accuracy from all upstream analysts). The interdependencies are largely based on the collection and dissemination of data from the data dictionary.

Figure 5 lists the main tasks associated with the interchange of data. The tasks are specific behaviors representing interactions among members (i.e., in this case, interactions associated with collection and dissemination of data). A matrix was

Discipline & Model		Tasks	Communication	Coordination	Monitoring	Feedback
POST-INTROS	Vehicle Closure	1. Select project	x			
		2. Obtain ModelCenter file	x	x		
		3. Run application (analysis) locally				
POST-CONSIZ		3.1 Perform various calculations				
		3.2 Collect results in data dict			x	x
		4. "Publish" data	x		x	x
HAVOC						
	Safety & Reliability	1. Select project	x			
		2. Obtain ModelCenter file	x	x		
		3. Run application (analysis) locally				
FIRST		3.1 Select appropriate input variables			x	x
		3.2 Perform various calculations				
		3.3 Collect results in data dict			x	x
		4. "Publish" data	x		x	x

Figure 5. Engineering team process model – ISAT specific.

developed with these tasks along the rows; columns represent each of four specific team processes observed to be related to performance outcomes (i.e., observed from task analysis and critical incidents of ISAT performance). The processes associated with ISAT during actual collaborative tasks are communication, coordination, monitoring and feedback. An 'x' is placed in each cell where a process is most relevant to improving or detracting from performance. For example, communication and coordination are important when obtaining the proper file to be assessed (i.e., so that the proper vehicle is assessed). Monitoring and feedback are likewise important when 'uploading' the data once it has been assessed to ensure quality control. For instance, errors made upstream

can prove costly for downstream members (e.g., when errors are caught all affected may have to re-perform their analyses). Instituting these four processes – or ensuring their viability – would improve efficiency, reduce haphazard errors, and reduce wait time. This approach to model development could be generalized to most any team. Likewise, Figure 5 only represents a portion of the ISAT team's individual disciplines. It is logical to assume that the model may be extended to all discipline interactions to the extent that such interactions are similar.

Model Assessment

There are a variety of methods available to measure human behavior (e.g., observation, self-report, peer-report, etc.). Each has costs and benefits. While it may be optimal to have an objective observational method in place in which expertly trained observers rate individuals in certain areas, it is not always practical. Therefore, those interested in assessing psychological constructs often use self-report data. There exists a general problem with self-report data, however, in that in some instances, individuals tend to rate themselves spuriously high in comparison to peer or supervisors' ratings (see Mount & Scullen, 2001). This may be due to a better understanding of oneself (as may be the case with measures of 'hidden' constructs such as motivation), due to the desire of the individual to be viewed in a more favorable light, or potentially, due to geographic dispersion (e.g., when assessing non-collocated team members – team constructs). We chose to utilize self-report assessments to demonstrate proof of principle of the engineering process model and the effects of geographic dispersion on collaborative engineering. For that purpose, self-assessments proved useful.

Team Process Measures

The ISAT-specific engineering process model (Figure 5) identifies four team processes relevant to team performance. Those include communication, coordination, monitoring and feedback. Rosenstein (1994) reported on the psychometric properties of scales measuring these constructs. The measures (see Appendix) were adopted for use with ISAT. Rosenstein (1994) demonstrated construct validity of the measures (i.e., there is evidence that the tests measure their purported constructs) and provided congeneric reliabilities for the scales: .91 for communication, .81 for coordination, .73 for monitoring and .81 for feedback. Each of these exceeds the recommendation by Nunnally and Bernstein (1994) of using scales with a minimum internal consistency of .70. The measure provides a definition of the construct (e.g., communication) and asks each team member to rate a set of items on a scale of 1 (almost never) to 5 (almost always) regarding how often team members engaged in each behavior.

Another issue that arises in using self-report data for team level constructs is the issue of agreement and aggregation. Rousseau and others (Rousseau, 1985; Roberts, Hulin & Rousseau, 1978) argued that it is appropriate to use individual level data to represent a higher-level (e.g., a team, workgroup, etc.) only when sufficient evidence exists as to the agreement of those individuals. A simple example will clarify this. Suppose that several members of a team were asked to rate the team's level of cohesiveness on a scale of 1 (not at all) to 5 (extremely). If half of the members rated the team a 5 and the other half a 1, their average would be a 3. One would ask if "3" was an accurate depiction of the team's cohesiveness. Certainly there is disagreement among the members, and the average is not meaningful in depicting the team level construct. However, the

disagreement may prove useful in identifying problem areas for the team (i.e., why is there disagreement – communication problems? in-group/out-group issues?).

James, Demaree and Wolf (1984, 1993) developed a method for assessing within-group agreement (r_{WG}). The procedure that they proffered compares the variance associated with the individual raters and items with a theoretical null variance that would be expected due to chance. Within-group agreement is calculated by the following formula:

$$r_{WG(J)} = \frac{J[1-(\overline{s_{xj}^{2}} / \sigma_{EU}^{2})]}{J[1-(\overline{s_{xj}^{2}} / \sigma_{EU}^{2})] + (\overline{s_{xj}^{2}} / \sigma_{EU}^{2})}$$

where $\overline{s}_{xj}^{\,2}$ is the mean of the observed variances on *J* essentially parallel items, and σ_{EU}^2 is the variance on x_j that would be expected if all ratings were due exclusively to random measurement error – the null variance. James et al. (1984) provided a method for determining the theoretical null variance for a variety of occasions (e.g., a rectangular, uniform distribution, triangular distribution in which central tendency bias is present, and a negatively skewed distribution in which there is a bias towards positive ratings).

It is reasonable to assume that members of a team may rate themselves in a favorable light. That is, in assessing psychological constructs related to team performance, the distribution of self-report scores may be negatively skewed (i.e., a positive bias). Therefore, in assessing r_{WG} it is appropriate to evaluate the null distribution based on such a hypothesis. James et al. (1984) suggested using .90 for a null variance with a moderately negative skew when a 5-point rating scale is used.

A rule-of-thumb has been suggested that values for r_{WG} of .70 or greater sufficiently justify aggregation of data to the higher-level (Cohen, Doveh, & Eick, 2001). This means,

given sufficient agreement of the team members (i.e., $r_{WG} \geq .70$) then the mean of their individual scores may be used to represent the team-level construct.

Team Processes – ISAT

The team process measures were distributed to the ISAT members during a November 2001 workshop. This workshop was conducted to familiarize the members with the deployment of PDM to further enable distributed collaboration. The general findings are presented in Table 1. In all, five individual members responded to the survey representing four ISAT disciplines (i.e., vehicle closure, safety & reliability, costs, and operations). The overall purpose of the self-assessment was to gain an understanding of the effect of the geographic distribution of the members and the technology used on the relevant team processes.

Table 1. Summary of ISAT responses to team process measures.

	Communication	Mutual Performance Monitoring	Intra-team Feedback	Coordination	Performance
$\overline{s}_{xj}^{\,2}$	.33	.89	.82	.68	.42
r_{WG}	.95	.10	.46	.75	.91
Mean	4.27	**	**	3.87	4.24

Note. r_{WG} was calculated using a moderately skewed null distribution. Anchors for the scales were 1 (almost never) to 5 (almost always).

** Due to lack of agreement, calculation of a mean is not appropriate for representing the team-level construct.

The ISAT members indicated that two of the team processes and a self-rating of performance were high. They were in relative agreement (i.e., $r_{WG} \geq .75$) for communication, coordination and performance and indicated a generally high score (mean ≥ 3.9) for those three measures. As for mutual performance monitoring and intra-team feedback, the members were in disagreement ($r_{WG} = .10$ and .46 respectively). This prohibits us from using the mean scores for these constructs in a meaningful manner. However, the fact that there is a discrepancy may be helpful in determining team needs. This may illustrate problem areas that can be improved with infrastructure changes (e.g., technological advancements facilitating mutual performance monitoring).

Concluding Remarks

The general aim of this project has been to develop a methodology for the assessment and continuous improvement of engineering team effectiveness in distributed collaborative environments. This has largely been accomplished through the observations and assessment of a specific engineering team, ISAT, as it transitioned from a fully collocated team to a geographically dispersed team. Relevant processes from several domains (i.e., organizational & human factors psychology) were used to develop a model that proved helpful in identifying team needs.

The team processes, communication, mutual performance monitoring, intra-team feedback, and coordination were deemed relevant to ISAT's performance from both a thorough review of the literature and appropriate team task analysis. These processes were used to develop an engineering team process model specifically for ISAT (see Figure 5). This model is composed of a matrix with the team tasks associated with

interdependence orthogonal to team processes. The model is important in that it identifies both areas of interdependence and the nature of the team processes relevant to those interdependencies. A similar model would be developed for other teams using the approach outlined in the Team Process Improvement Model (Figure 2).

Once the processes salient to team effectiveness had been identified, we were able to assess the team in terms of how the processes were affected by the team's recent changes (i.e., geographic dispersion). That is, team members were surveyed using a self-report instrument. Information from this questionnaire identified problem areas for the team. In this case, team process barriers were identified by the members relative disagreement in conjunction with critical incidents (Fletcher, 2001a). Team members were not in agreement on the extent of mutual performance monitoring and intra-team feedback in the team. This could likely be improved with advancements in the collaborative tools that they use. For instance, by implementing a monitoring system within the PDM (or other technology) data integrity may be automatically monitored and reports could be automated. Of course, these are only recommendations and are not the only plausible reasons for team member disagreement. It should not be overlooked that the members view the team as high in communication and coordination despite the challenge of geographic dispersion.

Overall, the aim has been met. A methodology of continuous assessment aimed at improving team process has been proposed. Further, by using a particular engineering team, ISAT, we were able to demonstrate that a team specific model could be generated to detail the salience of certain team processes. By using a psychometrically sound self-report instrument, we were able 'ask' the particular team members how they were

affected by geographic dispersion – simultaneously demonstrating proof of principle for the methodology and identifying particular concerns for the collaborative engineering team in distributed environments.

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Appendix

Teamwork Components Rating Scale

Instructions:

Using the rating scale below, please rate the teamwork behaviors you saw the ISAT team exhibiting. Please think of the most recent assessment; include experts from all models and disciplines involved in the assessment when considering *team members*. This questionnaire is for developmental purposes only; your responses will remain confidential. Insert your answers into the document; save; and e-mail as an attachment to tom.fletcher@verizon.net.

Almost Never		Sometimes		Almost Always
1	2	3	4	5

Write "N/A" if a behavior does not apply

Communication: Communication involves the exchange of information between two or more team members in the prescribed manner and by using proper terminology. Often the purpose of communication is to clarify or acknowledge the receipt of information.

Team members:

1. _____ Clarify intentions to other team members.
2. _____ Clarify procedures in advance of assignments.
3. _____ Pass complete information as prescribed.
4. _____ Acknowledge and repeat messages to ensure understanding.
5. _____ Communicate with proper terminology and procedures.
6. _____ Verify information prior to making a report.
7. _____ Ask for clarification of performance status when necessary.
8. _____ Follow proper communication procedures in passing and receiving information.
9. _____ Ensure that members who receive information understand it as it was intended to be understood.
10. _____ Communicate information related to the task.
11. _____ Discuss task-related problems with others.

Monitoring: Monitoring refers to observing the activities and performance of other team members. It implies that team members are individually competent and that they may subsequently provide feedback and backup behavior.

Team members:

1. _____ Are aware of other team members' performance.
2. _____ Are concerned with the performance of the team members with whom they interact closely.
3. _____ Make sure other team members are performing appropriately.
4. _____ Recognize when a team member makes a mistake.
5. _____ Recognize when a team member performs correctly.
6. _____ Notice the behavior of others.
7. _____ Discover errors in the performance of another team member.
8. _____ Watch other team members to ensure that they are performing according to guidelines.
9. _____ Notice which members are performing their tasks especially well.

Feedback: Feedback involves the giving, seeking, and receiving of information among members. Giving feedback refers to providing information regarding other members' performance. Seeking feedback refers to requesting input or guidance regarding performance. Receiving feedback refers to accepting positive and negative information regarding performance.

Team Members:

1._____ Respond to other members' requests for performance information.
2._____ Accept time-saving suggestions offered by other team members.
3._____ Explain terminology to a member who does not understand its meaning.
4._____ Ask the supervisor for input regarding their performance and what needs to be worked on.
5._____ Are corrected on a few mistakes, and incorporate the suggestions into their procedures.
6._____ Use information provided by other members to improve behavior.
7._____ Ask for advice on proper procedures.
8._____ Provide helpful suggestions to other members.
9._____ Provide insightful comments when an assignment does not go as planned.

Coordination: Coordination refers to team members executing their activities in a timely and integrated manner. It implies that the performance of some team members influences the performance of other team members. This may involve an exchange of information that subsequently influences another member's performance.

Team members:

1. _____ Complete individual tasks without error, in a timely manner.
2. _____ Pass performance-relevant data from one to another in an efficient manner.
3. _____ Are familiar with the relevant parts of other members' jobs.
4. _____ Facilitate the performance of each other.
5. _____ Carry out individual tasks in synchrony.
6. _____ Cause each other to work effectively.
7. _____ Avoid distractions during critical assignments.
8. _____ Carry out individual tasks effectively thereby leading to coordinated team performance.
9. _____ Work together with other members to accomplish team goals.

Performance: Performance concerns the accomplishment of the activities and tasks required of the team. This team performance occurs with a consideration of the goals and expectations of team members, the supervisor, and the larger organization.

Team members:

1. _____ Accomplish team goals.
2. _____ Meet or exceed expectations of the team.
3. _____ Meet performance goals in a timely manner.
4. _____ Regard team output as adequate or acceptable.
5. _____ Achieve team goals with few or no errors.
6. _____ Produce team output that meets standards of the organization.
7. _____ Regard accomplishments of the team to be above average.
8. _____ Feel that the team as a whole performed at an acceptable level.
9. _____ Met team objectives in an efficient manner.

Discipline: Vehicle Closure____ Safety & Reliability___ Operations___ Costs & Economics___

Please indicate tool used:

Vehicle: TSTO parallel glideback___ TSTO parallel burn flyback___ TSTO serial flyback__

Annex D

Virtual Collaborative Environments for System of Systems Engineering and Applications for ISAT

Virtual Collaborative Environments for System of Systems Engineering and Applications for ISAT

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Abstract. This paper describes a system of systems or metasystems approach and models developed to help prepare engineering organizations for distributed engineering environments. These changes in engineering enterprises include competition in increasingly global environments; new partnering opportunities caused by advances in information and communication technologies, and virtual collaboration issues associated with dispersed teams. To help address challenges and needs in this environment, a framework is proposed that can be customized and adapted for NASA to assist in improved engineering activities conducted in distributed, enhanced engineering environments. The approach is designed to prepare engineers for such distributed collaborative environments by learning and applying e-engineering methods and tools to a real-world engineering development scenario. The approach consists of two phases: an e-engineering basics phase and e-engineering application phase. The e-engineering basics phase addresses skills required for e-engineering. The e-engineering application phase applies these skills in a distributed collaborative environment to system development projects.

1. Introduction

1.1. Background

The effects of globalization are dramatically changing the practice of engineering and technology in the areas of enterprise project activities and advanced engineering environments. The National Research Council's (NRC's) Committee on Advanced Engineering Environments expects further significant changes in engineering product design, project processes, as well as collaboration support, education and training within the near future (NRC, 2000). Product design and analysis is increasingly using web-based systems to assist the communication

between distributed team members. Attempts are being made to collapse project processes in terms of steps and time requirements in order for enterprises to increase engineering team efficiency. Organizations, such as the National Aeronautics & Space Administration (NASA), are conducting pilot enhanced engineering initiatives to help assess whether design and analysis teams can be distributed and more engineering activities combined or conducted in parallel to compress the resources and time required for front-end engineering efforts. Distributed collaboration systems to support such efforts are growing more and more complex, including grid-like network infrastructures connecting team members with secure high bandwidth, shareable distributed engineering data artifacts, distributed engineering tool sharing, and synchronous audio and video.

1.2. Global e-engineering environment

This resulting global enterprise environment is complex, dynamic, and produces many collaboration challenges among product development and manufacturing teams, as shown in Figure 1. Global presence means geographically distributed team members from diverse organizational and national cultures. Global organizations and collapsed project engineering cycles can create team instability as various skills are quickly applied to product design challenges. Unfamiliarity between team members is more likely due to less face-to-face interaction. Project characteristics will include reduced development cycles, greater engineering complexity, increased integration, and tighter budgets. Generating success in the new reality of global enterprises is much different than what was required in traditional engineering environments. Enterprises will need to transform and ensure product development teams thrive

in a virtual collaborative engineering environment. This environment and the teams working in it must be capable of high collaborative performance conducive to innovation within dynamic schedule, cost, and performance constraints.

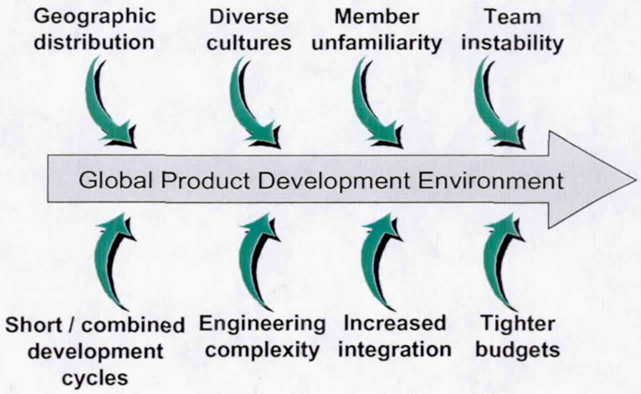

Figure 1. Global product development environment challenges.

We are calling teamwork in this environment, ***e-engineering***, which is defined as 'distributed collaboration in cyberspace using leading edge technologies enabling physically-dispersed, diverse teams to create integrated, innovative and competitive products, systems, and services.' According to National Research Council studies (1999, 2000), an ideal virtual collaborative engineering environment or Advanced Engineering Environment (AEE) would 'accommodate diverse user groups and facilitate their collaboration by helping to eliminate cultural barriers between groups from different parts of an organization, different organizations, or different areas of the world. There are a number of important benefits that can be achieved from effective team use of virtual collaborative engineering technologies and methods as follows (Mills, 1998):

- *Lower product development, design and production costs.* Cost is the first and foremost factor driving much of the interest in VCE technologies. Products can be developed with more interaction in less time at a reduced cost. This greater interaction and more rapid development time are accomplished through use of unique techniques and capabilities provided within a VCE environment.
- *Effective information sharing and generation.* The ability to easily share resources from remote sites is a critical component of a VCE environment. This allows all involved team members to access data, drawings, and documents to enhance design development and more quickly deal with specification changes. Such information sharing also provides an ability to evaluate the use of cutting edge technology early in the process and makes industry expert consultants more accessible. Sharing of information also enables team members to have a common understanding of all issues involved.
- *Improved communication.* The application of VCE removes geographical constraints and reduces time lost in traveling. It facilitates an enriched communication between and among participants. Team members will interactively evaluate virtual prototypes of product designs and evaluate alternative scenarios. They will be able to make decisions quicker since all team members share the same information.
- *Improved development programs.* VCEs will link physically dispersed teams for an integrated product and process development. This allows suppliers, users, and clients to provide feedback early in the engineering cycle, which enables team members to incorporate product lifecycle concerns. Such integration will also have an impact on the product quality.

In the following sections, we propose a system of systems or metasystems approach to e-engineering that can assist rapidly-organized project teams in meeting the challenges and needs of global engineering and manufacturing enterprises in virtual collaborative environments (VCEs). Applications of this approach to an ISAT case scenario are also described. Viewing enhanced distributed e-engineering environments as a metasystem provides several guiding principles from which to approach this problem. Systems of systems must be engineered in terms that provide effective design, deployment, operation, transformation, and evaluation. These new "higher order" systems must be focused on producing "systems of systems" performance as opposed to individual performance of subordinate systems. The design, deployment, operation, and transformation of higher level metasystems involve the integration multiple complex system processes to produce desirable results. These metasystems are themselves comprised of multiple autonomous embedded complex systems that can be diverse in technology, context, operation, geography, and conceptual frame. (Keating et. al., 2002). At the "metasystem" level, true optimization is a fallacy. Complex turbulent contexts and environments preclude optimization in the traditional systems engineering sense. Satisficing suggests that SoSE should focus on development of satisfactory solutions that are a continual refinement of the e-engineering environment. This perspective appreciates the continual evolution and tailoring of e-engineering system problem(s) requirements, boundaries, entities, and relationships throughout the a project's e-engineering effort.

2. Concepts for the e-engineering project cycle

In order to help address the above challenges for global engineering, an important research question is 'what changes are required for rapidly-organized engineering teams to quickly assimilate and execute at high e-engineering performance levels and how can these changes be quickly implemented and sustained?' In order to provide some foundation to address this question, it is useful to first discuss selected project characteristics and virtual team concepts. This discussion will also help answer the portion of the research question concerning what critical adaptation areas are useful for project teams to perform at high e-engineering levels.

Project characteristics serve to partially define work conducted in virtual collaborative engineering environments. A project can be defined as 'a temporary endeavor undertaken to create a (deliverable) unique product or service' (PMI Standards Committee, 1996). Project phases are collectively known as the project life cycle, which defines a project's beginning, phase sequencing, and end.

Many models exist for project life cycles (Dorfman, 1977). One extensively used model is the waterfall model containing sequential phases of requirements, design, build, test, and integration. Each waterfall phase should be essentially complete before the next phase begins. This model encounters problems when project requirements do not remain stable following completion of the requirements phase. One approach to enhancing the waterfall model is the prototyping model, which makes use of system prototypes with selected functionality to help determine accurate requirements. These prototypes are developed using compressed waterfall sub-models early in the requirements phase of a traditional waterfall model.

The spiral life cycle model (Boehm, 1988) is an innovation that permits combinations of conventional (e.g., waterfall) and enhanced (e.g., prototyping) to be used for various portions of

a project. Recently, the spiral model has been clarified by Boehm (2000) to capture its essence. Spiral development is a risk-driven process model generator with two main features. The first feature is a cyclic approach to incrementally grow a project's degree of definition while decreasing its degree of risk. The other main feature is the use of anchor point milestones to ensure stakeholder review and commitment during spiral cycles. Boehm has also clarified that the spiral model is not just a sequence of waterfall increments with activities following a single spiral sequence. On the contrary, the order of activities in the spiral is a guideline with the actual order of visiting or revisiting activities driven by ongoing project assessments. It is also important to emphasize that the spiral model is a process-oriented model where each cycle includes assessment and improvement of project processes as well as project deliverables.

Spiral development has a focus concerning software projects (e.g., Muench, 1994), but can be applied more generally to project life cycles, including e-engineering projects. The spiral model's emphasis on improving both project processes and deliverables fits well with the challenges of integrating e-engineering process improvements during the project life cycle. With the expected compression of project timelines and constrained budgets in advanced engineering environments, the spiral model's cyclic development approach and embedded iterative risk assessments can accelerate e-engineering team development, accurate project requirements definition and decrease project uncertainty and risk. The anchor point milestones can serve to formalize progress concerning e-engineering performance levels, as well as the approval and hand-off of external deliverables.

6. E-engineering interactions, dynamics, and technology environment

One critical aspect of e-engineering is for project teams to understand and apply the various types of distributed collaborative interactions. A general model of distributed collaboration dynamics is shown in Figure 2 (Dix et. al., 1998). A common environment is established and entities populate the environment, including project participants (e.g., team members and external stakeholders) and artifacts (e.g., documents and virtual or physical prototypes). Interactions can occur between participants and between participants and project artifacts. Direct communication interactions are conducted between participants using synchronous and asynchronous tools, including audio, video, and text messaging. Participants interact with project artifacts by controlling artifacts and receiving feedback using artifact tools. Participants also indirectly interact with each other through these artifact tools. Two forms of this indirect interaction are feedthrough and deixis. Feedthrough occurs when a participant's manipulation of shared artifact objects is viewed by others (e.g., rotation of a 3D CAD design). Deixis occurs when referencing an artifact aspect to other project participants (e.g., pointing with a cursor to a feature of the CAD drawing).

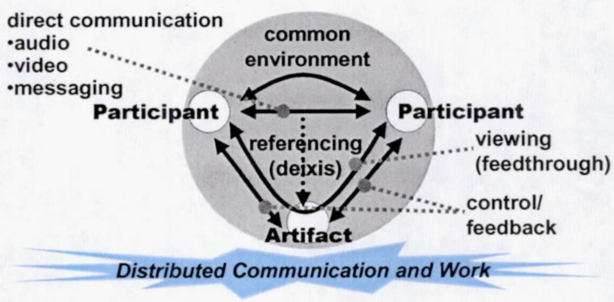

Figure 2. Distributed communication and work interactions.

This distributed collaboration interaction model can be extended and viewed more analytically in terms of an object-oriented approach to project processes and interactions.

Object-oriented extensions could be especially useful for modeling distributed collaborative processes in specific project scenarios. One object-oriented approach to business modeling treats project processes as objects, as well as other entities of the application domain (Bider & Khomyakov, 1997). In terms of the above distributed project collaboration model, objects can include entities (such as virtual team members, data artifacts, and supporting collaboration tools), as well as the interactions (such as direct communication and data artifact interactions) between such entities. In this domain, relations between conceptual objects are as important as objects themselves and entity interactions are active, not passive. Such distributed collaboration objects are complex and dynamic and the properties of objects can be represented with the help of: history, events, and activities. History is the time-ordered sequence of all the previous states of objects. The time-ordered history is most important for objects that represent collaborative processes as it shows the evolution of the process in time. Events present additional information about transitions from one state of an object to another, including date, time, impacted objects, and event attributes. Activities represent distributed collaboration actions that take place in the project domain, like the various types of collaborative model interactions described above.Such a distributed communication and work interaction model is now enhanced to represent e-engineering interactions and associated technology areas to enable this interaction, as shown in Figure 3. The two main areas are user-centric tools, representing direct participant-to-participant communication and artifact-centric tools, representing participant-to-artifact interaction. User-centric tools can take both asynchronous (e.g., email) and synchronous (e.g. electronic conferences, video connections, audio, and text messaging) direct communication forms. Artifact-centric tools can include project management and scheduling applications, product and process simulation, and discipline-specific tools needed for various project deliverable scenarios.

The same categories of groupware interactions from Figure 2 also apply and are shown in Figure 3. In order to conduct such interactions in a globally distributed environment, various technology layers are represented. A human-computer interaction (HCI) layer needs to exist between participants and the people or artifact-centric application tools. Such HCI technology includes computer input and display devices. Application interfaces are required to transfer communications and artifact data between various project applications. These interfaces involve translation protocols and data format standards. Network infrastructures need to exist to transmit interaction data to other distributed locations via local and wide area networks. A knowledge repository can also be incorporated to manage a complex project's artifacts, facilitating configuration management and quality control.

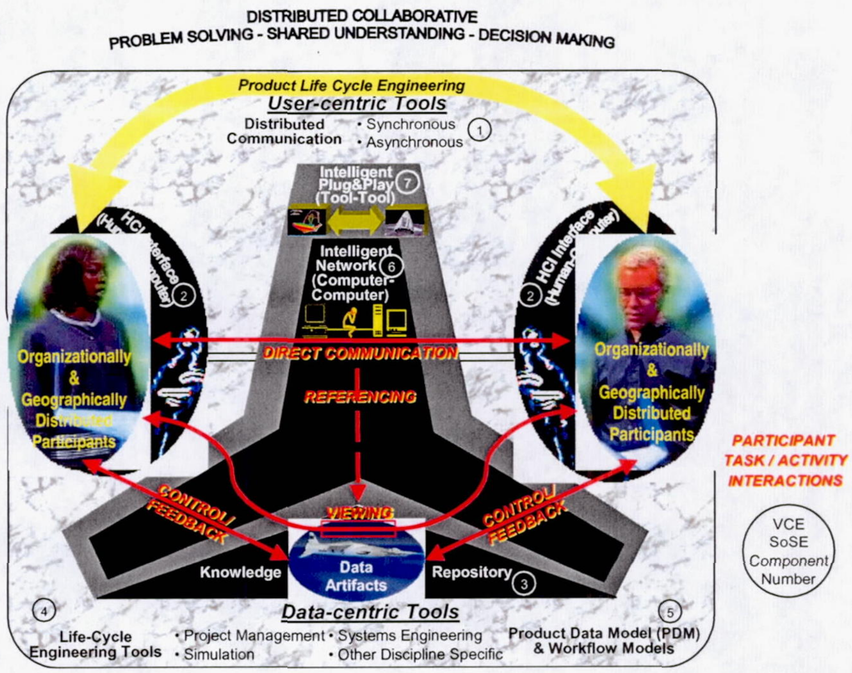

Figure 3. Virtual collaborative metasystem distributed interaction environment

It is important for e-engineers to understand the above technology areas involved in distributed collaborative work environments. Critical issues in applying this technology include

defining user requirements, tool selection, network requirements, systems requirements, and emerging technology standards. Obtaining user requirements for collaborative tool use in projects can be difficult and requires personnel with a good technical understanding of collaborative tools as well as project tasks. The team leader and members must coordinate with information technology staff in developing these requirements. One option is to develop a "strawman" list and present this list to a group of team members for validation. With a completed list of requirements, tools are identified to meet the stated requirements from the existing collaborative toolset in the organization or adding additional tools. Network requirements also need to be taken into consideration, since deploying collaborative tools can have a severe impact on a network. In order to get the distributed collaboration infrastructure working (especially between organizations), firewall security issues need to be resolved as well as the environment's impact on network bandwidth. System requirements for the e-engineering environment can include upgrade of hardware peripherals, including headsets and desktop cameras for videoconferencing. The existing technology infrastructure needs to be leveraged as much as possible, since a majority of required e-engineering capabilities can typically be met with existing tools.

The issue of open standards is also important to understand when deploying and upgrading e-engineering infrastructures. Emerging standards for distributed collaboration include T.120 standards addressing real time data conferencing (audiographics), the H.323 standard addressing video (audiovisual) communication on local area networks, and the H.324 standard addressing video and audio communications over low bit rate connections such as modem connections. Even though these standards are being widely used, many tools still are using proprietary protocols and this can impact integration of these tools within a distributed project environment.

Virtual team and task dynamics

Another aspect of e-engineering interactions deals with team and task dynamics during projects. The task performance of teams using e-engineering technology to communicate and collaborate can be viewed as a series of stages (McGrath, 1990). These task stages are 1) *inception*, 2) *problem solving*, 3) *conflict resolution*, and 4) *execution*. Inception involves defining project goals. The problem solving stage deals with development of solutions to project technical problems. Conflict resolution occurs when different points of view and approaches need to be reconciled. Also, different cultural and organizational perspectives could require resolution. Finally, execution involves performing project tasks and overcoming project and organizational barriers that inhibit performance. These task dynamic stages are not necessarily sequential and certain stages may not be required, depending on the project scenario and complexity. A team might go from inception directly to execution for more repeatable, prescriptive project scenarios or repeat iterations between problem solving and conflict resolution with difficult scenarios. Duarte & Snyder (1999) have identified four virtual team social dynamic stages, which parallel the above task dynamics. Social stage 1, *interaction and inclusion*, is where the team identifies and maps individual skills to project needs, establishes communication and work procedures, and develops initial plans. Social stage 2, *position status and role definition*, involves member role definition and status relationships. In social stage 3, *allocation of resources and power*, the team addresses allocation of resources and member power relationships. Social stage 4, *interaction and participation*, involves performance of

collaborative work including interaction, participation among the team members, and overcoming productivity barriers.

Implementation issues

Understanding and developing proficiency in the above aspects of virtual team interactions and dynamics are essential for attaining rapid, high performance levels in e-engineering environments. Collaborative interaction and technology areas, as well as task and social virtual team stages are critical e-engineering areas to understand, establish, and continually improve during the project life cycle. Initial assessments need to be made of team member global distribution, technology capability, and skill levels in distributed collaboration as well as relevant engineering-specific disciplines. Individuals and the entire team need to be trained in identified e-engineering skill and knowledge area deficiencies. Virtual collaborative functionality needs should be mapped to project activities and technology solutions identified to enable this capability. Collaboration technology, task, and social processes should be iteratively assessed and continually improved during the project life cycle.

4. The model for e-engineering team adaptation (MeTA)

Now that a foundation of literature has been discussed and e-engineering-related concepts identified, an initial framework is proposed, called the Model for e-engineering Team Adaptation (MeTA) to help improve the performance of such global engineering teams. As part of a word's structure, *meta* can indicate change, (e.g., metachromatism – a change in an organism's color

caused by variation of physical conditions). Similarly, MeTA can be thought of as a framework of changes implemented to a project team's dynamics, required by varying the team's physical and information technology environment to virtual collaborative engineering. The model, which is pictured in Figure 4, uses an adaptation of the spiral software development approach (Boehm, 1988), to integrate e-engineering process and product development activities. In order to quickly 'spin up' to high project performance, the team conducts various e-engineering process and product-centric cycles.

MeTA is a process-oriented model where each cycle includes assessment and improvement of project processes as well as project deliverables. Similar to other spiral models, each cycle of the model goes through actions portrayed as a quadrant. MeTA uses action categories of identify, plan, execute, and assess. The model has two main phases in the spiral itself: e-engineering basics and e- engineering application. As with the general spiral development model, MeTA is not just a sequence of waterfall increments with activities following a single spiral sequence. The order of activities in the spiral is a guideline with the actual order of visiting or revisiting activities driven by ongoing project assessments. In fact, project activities or sub-activities could be happening simultaneously in multiple MeTA cycles or phases. Anchor point milestones reviews are conducted in the assessment actions quadrant concerning e-engineering performance levels and external deliverable progress and hand-offs.

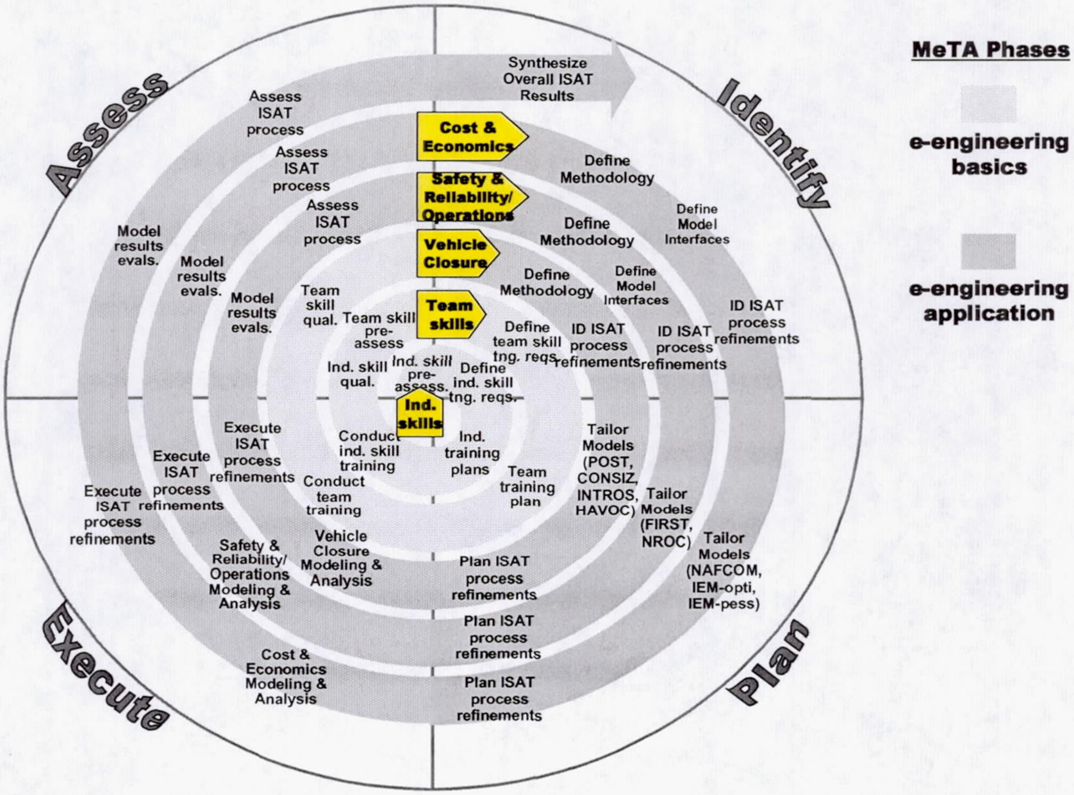

Figure 4. Model for e-engineering team adaptation (MeTA) phasing and sample ISAT Case activities.

4.1. The e-engineering basics phase

The focus of the MeTA basics phase deals with an engineering team quickly reaching proficiency in basic e- engineering process areas. In this area of the model, both individual and team e-engineering skill cycles are addressed. MeTA action quadrants of identify, plan, execute, and assess are used to bring the team to required skill proficiency. For both the individual and team skill cycles, proficiency assessments are initially conducted by the team leader or an external source.

E-engineering skill deficiency areas are identified and individual training is planned and executed to achieve proficiency in these areas. Individual training is then followed by individual qualification assessments to establish proficiency. Individual areas can include collaboration tool skills and virtual team process concepts, project management and scheduling, as well as engineering-discipline skills required for a specific project scenario.

The team skill cycle also starts with initial proficiency assessments of the team's e-engineering performance, by the team itself or by external evaluation. E-engineering team deficiency areas are identified and team training and exercises planned and executed to achieve proficiency in these areas. Team training is then followed by team qualification assessment to establish proficiency. Teaming skills include performing at proficient levels in virtual team task and social dynamics as well as working effectively using distributed synchronous and asynchronous collaboration tools.

4.2. The e-engineering application phase

In the second MeTA phase, application, the focus shifts to the team applying its e-engineering proficiency to system development or other deliverable goals. This does not mean that e-engineering process refinement activities are over, just that they are now focused on supporting project development goals. MeTA action quadrants of identify, plan, execute, and assess are now used to support iterative project deliverable development cycles. In Figure 4, the e-engineering application area is tailored to the ISAT case scenario, with vehicle closure, safety & reliability, operations, and cost & economics modeling and analysis cycles.

It should be stressed that MeTA cycles and activities should be tailored to specific e-engineering project scenarios, but there are certain MeTA 'invariants' that define the essence of this model. These invariants use Boehm's spiral software development model invariants (Boehm, 2000) as a start point. The first invariant is that MeTA is a process-driven model, concerned with a team's e-engineering process improvement as well as deliverable task progress. As such, MeTA must contain phase areas directed at e-engineering process proficiency (e.g., basics phase) as well as deliverable progress (application phase). The second invariant is that MeTA is a risk-driven assessment model where iterative process and deliverable assessments determine the type and level of effort of upcoming activities. The sequence of spiral activities is just a guide. In reality, project activities or sub-activities in multiple cycles could happen simultaneously in multiple MeTA cycles or phases, depending on these project assessments. The third invariant is that MeTA contain anchor point milestones formalize progress concerning e-engineering performance levels, as well as the approval and hand-off of external deliverables

6. e-Engineering applications to an ISAT case scenario

NASA's Inter-center Systems Analysis Team (ISAT) is conducting a pilot enhanced distributed engineering initiative. ISAT engineering analysis activities include individual assessment discipline teams conducting vehicle closure, safety and reliability, operations, and economic modeling, which are very sequentially interdependent. Following implementation of a semi-distributed environment and Product Data Management (PDM), several of the specific discipline activities became parallel in nature (Fletcher, 2001) with teams working independently before sharing model input and output parameters. Applications of the e-engineering approach

to the ISAT case scenario are now described. Figure 5 shows an e-Engineering ***Entity*** view of the ISAT case task environment, where entities include key participants (shown in yellow) and artifacts (shown in green) as described previously in Figure 3. Entities are organized in terms of analysis activities and general sequencing of these activities in the ISAT case scenario. Participants are also identified by team role and geographic NASA center location.

This e-Engineering Entity view is then enhanced to an Entity/Interaction view shown in the diagonal and upper portions of Figure 6. This can be treated as a type of systems engineering functional or behavioral view of the distributed engineering environment. This Entity/Interaction view is necessary to capture before e-Engineering infrastructure and methodologies are tailored and implemented for a program or project scenario. This view drives the type of technology implementations that can meet team distributed functionality needs for projects and work packages. Both user and data-centric interactions shown in Figure 3, which are necessary for effective performance of distributed ISAT analysis tasks, are mapped to scenario user and artifact entities. User-centric communication interactions include audio, video, and messaging interaction channels between participant users and analysis sub-teams. Data-centric interactions include shared application control, viewing, referencing, storage of artifact files, and sharing of project files. In terms of the ISAT scenario, Figure 6 shows the need for user-centric interactions at the overall ISAT team level, but also at each analysis sub-team level. All participants should have the capability to conduct synchronous dialog with other sub-team member and dialog between sub-teams on an individual or group basis. Such dialog is more natural with synchronous video, audio, and instant messaging capabilities. Also shown is the need for data-centric interactions within and between sub-teams. Within sub-teams, users need to be able to control, store, reference, and view modeling and analysis applications. Between groups, for

viewing and referencing interaction channels as well as file sharing are needed for ISAT team activities, including model error checking, model parameter input and output between dependent model interfaces, and synthesis of analysis across models.

Another logical view of e-Engineering entities and functional interactions is shown in Figure 7, which has similar information in a matrix organization. Entities are organized along the diagonal, with e-Engineering interactions shown at matrix intersections for participant – participant and participant-artifact interactions. ISAT Team interaction requirements are shown along the top row. Clusters of sub-team requirements are also shown for between participant and model interactions.

By comparing this functional view with current or proposed implementations, an e-Engineering impact analysis can be conducted to analyze the traceability of functional requirements to implementations. As an example, Figure 8 shows this integrated functional and implementation view using the observed implementation of the ISAT engineering environment. On the lower half of the view current e-Engineering technology and processes can be identified for team, participant, and data model interactions. User-centric communication was dominated by an overall ISAT team room videoconferencing between centers. Data-centric communication employed an enterprise product data model (PDM) solution, which allowed integration between standalone analysis models, data storage, and file sharing. An e-Engineering impact analysis of the ISAT case highlights priorities for improvement for future distributed environments.

ISAT e-Engineering traceability issue #1 deals with the inadequacy of room videoconferencing to meet user-centric communication needs. ISAT consists of multiple teams and a group audio and video channel is inadequate for user communications by individuals within and between teams. Possible technology solutions include multi-cast desktop

videoconferencing, similar to the e-Engineering classroom at Old Dominion University, which allows individual and group audio, video, and application sharing. Such tools should include the capability to interactively view any conference participant (whether speaking or listening), have a list of current participant names, allow file transfer, and whiteboarding.

ISAT e-Engineering traceability issue #2 also deals with the inadequacy of room videoconferencing to meet user-centric communication needs. As shown in the functional view, multiple conferences between participants and sub-teams could be required at the same time. With a one channel room videoconferencing solution, only one session can occur at a time within a collaborative area. Desktop videoconferencing or other multichannel solutions can allow for parallel distributed dialogs to occur, which maps better into the parallel nature of the ISAT workflow. Such simultaneous multiple conferences are possible within a single center's collaborative area, or from individual participant desktops.

ISAT e-Engineering traceability issue #3 deals with the ability remotely view, reference, and control data model applications. If analysis tasks are conducted on standalone computers, without the ability for application sharing, the collaboration workflow becomes more like information sharing, where model input parameter values and results are "throw over the wall" and transferred to the next analyst or sub-team. Application sharing is essential to remotely view, reference, and control data model applications between multiple team members, which can help in process and error checking, as well as compress analysis times and resources requirements.

6. e-Engineering ISAT case analysis conclusion

This section of the ISAT case research was conducted by Dr. David Dryer at Old Dominion University and contains a preliminary system of systems engineering approach for the iterative design, implementation, and improvement of e-Engineering project teams. This approach includes use of the MeTA model for quickly increasing and maintaining basic and applied e-Engineering proficiency. The approach also outlines a systems engineering process to assist in identifying distributed collaboration interaction requirements for a particular task environment, designing infrastructure solutions, and graphically assessing the traceability impact of current and proposed environments.

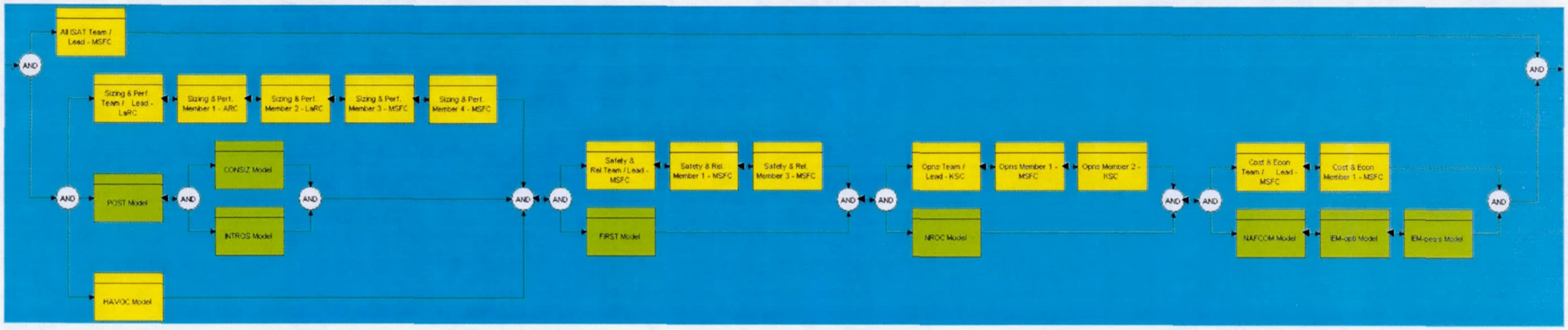

Figure 5. Entity (Participants and Model Artifacts) View of ISAT Case activities.

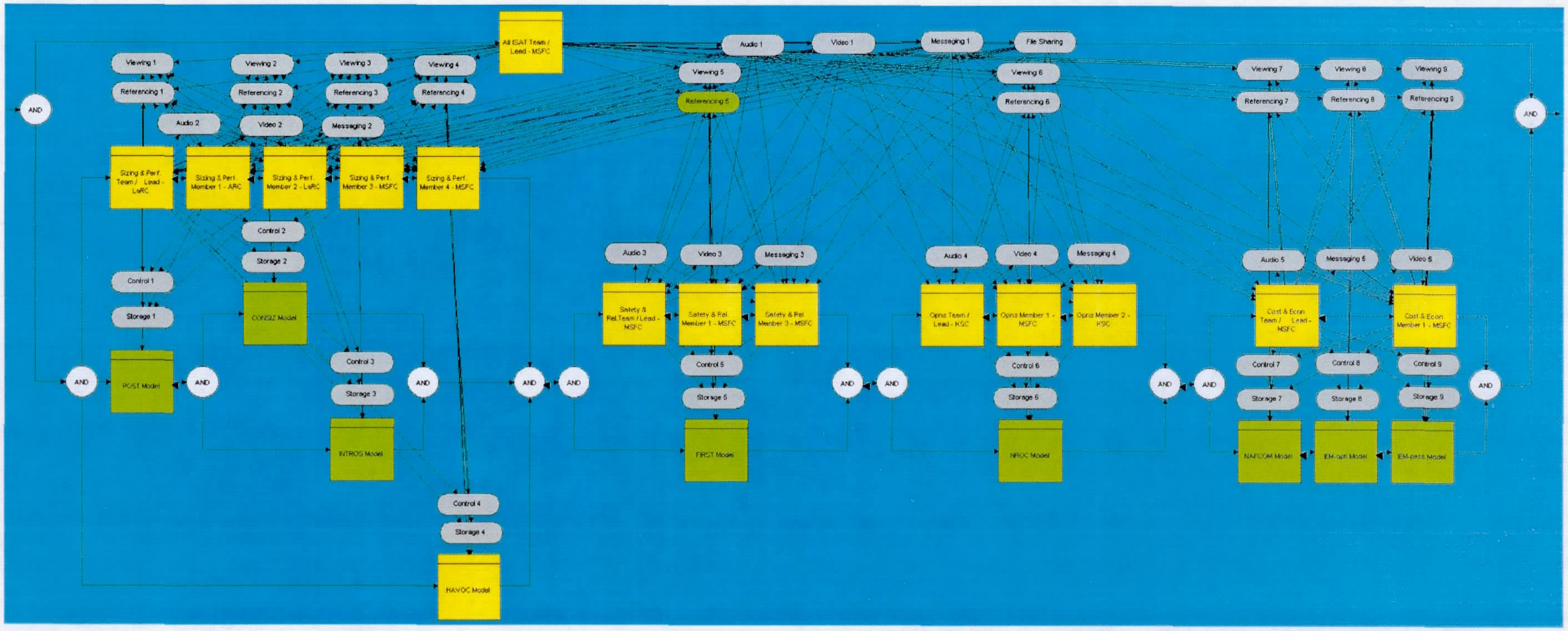

Figure 6. Enhanced Entity and e-Engineering Interactions (User and Data Centric) View of ISAT Case activities.

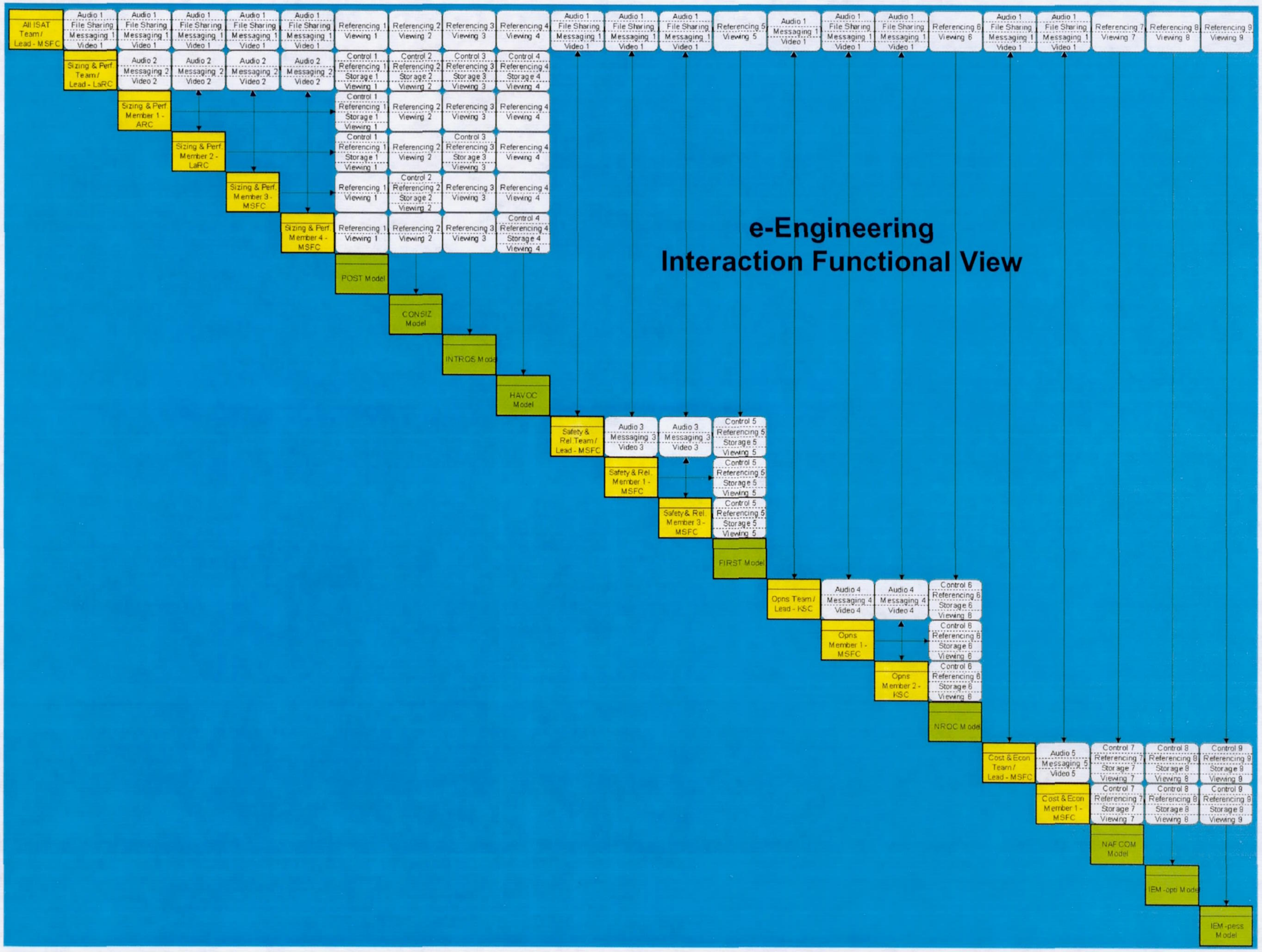

Figure 7. ISAT Case e-Engineering Entity/Interaction Functional View.

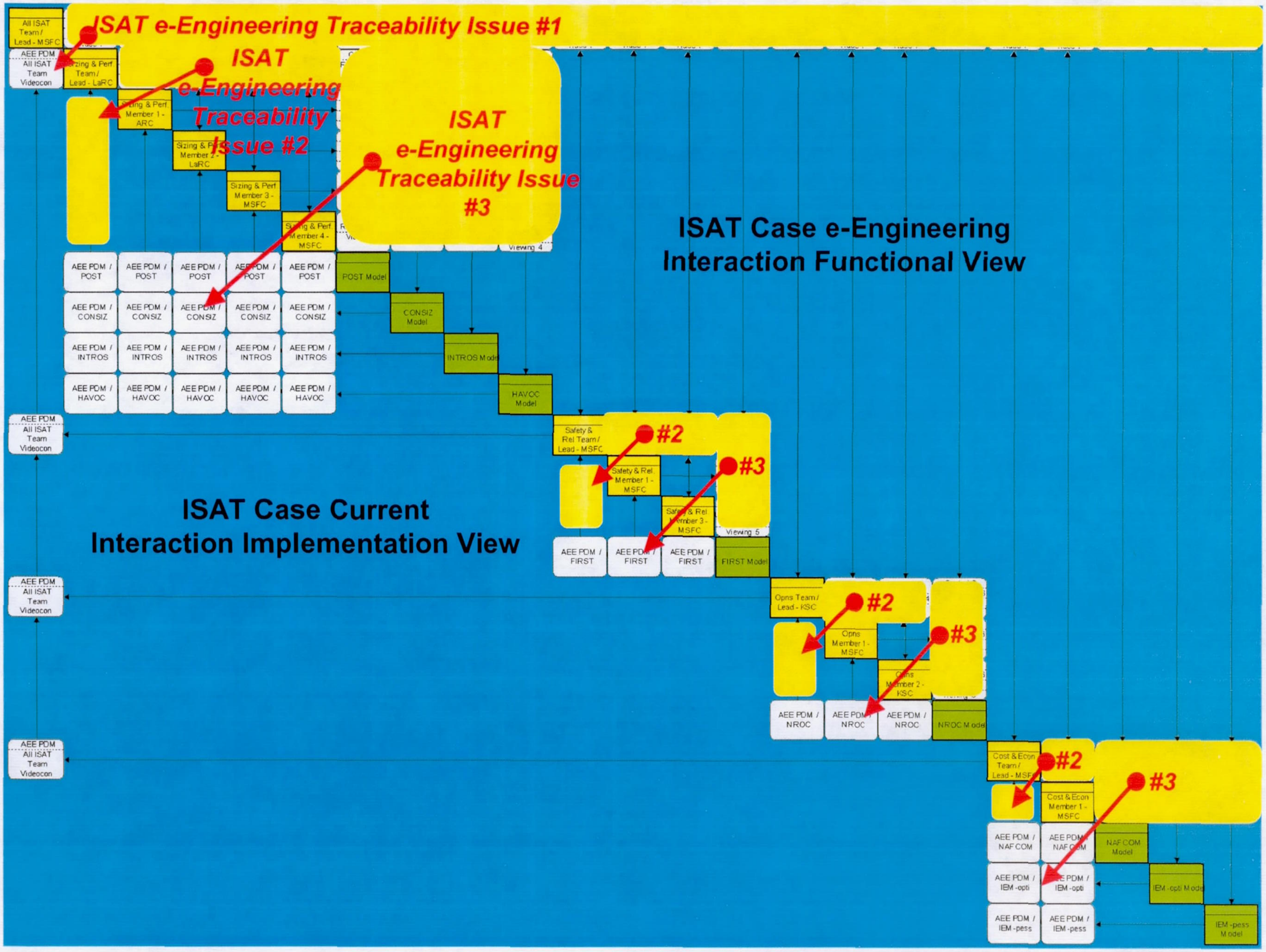

Figure 8. ISAT Case e-Engineering Functional and Current Implementation Views.

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